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International application number: PCT/US05/007363

International filing date: 07 March 2005 (07.03.2005)

Document type: Certified copy of priority document

Document details: Country/Office: US  
Number: 60/605,943  
Filing date: 31 August 2004 (31.08.2004)

Date of receipt at the International Bureau: 09 May 2005 (09.05.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)



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**APPLICATION NUMBER: 60/605,943**

**FILING DATE: August 31, 2004**

**RELATED PCT APPLICATION NUMBER: PCT/US05/07363**



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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)

Express Mail Label No. EL974046106US						
INVENTOR(S)						
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TITLE OF THE INVENTION (500 characters max)						
HIGH SPEED POSITION SENSOR						
Direct all correspondence to CORRESPONDENCE ADDRESS						
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ENCLOSED APPLICATION PARTS (check all that apply)						
<input checked="" type="checkbox"/>	Specification	Number of Pages	55	<input type="checkbox"/>	CD(s), Number	
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Application Data Sheet. See 37 CFR 1.76						
METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT (check one)						
<input checked="" type="checkbox"/>	Applicant claims small entity status. See 37 CFR 1.27				FILING FEE AMOUNT (\$)	
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Gerry A. Blodgett

## High Speed Position Sensor

### Abstract

Here is disclosed an induction position sensor suitable for high speed applications.

### Background

In order to improve performance of internal combustion engines it is desirable to be able to operate the engine valves by electronic means. Thereby eliminating the power consuming mechanical components that actuate the valves in prior art engines.

Electronic valve actuation also offers the ability to change valve timing by computer control for further benefits. In order to make a workable electronic valve actuator it is necessary to be able to sense the position of the valve in its movement. A sensor for this application must be able to work in the engine environment, be accurate in its output and rapid in its response time.

### Description of Embodiment

#### Sensor

Fig 1 shows a sectional view and an end view of a sensor of the current invention. Coil 1 is wound on bobbin 2. The coil is 227 turns of 28 gauge copper wire. Wire leads 7 run from the coil to the associated circuit. The bobbin is made of a suitable non-magnetic material, for example nylon. The bobbin and coil assembly is housed in housing 3, again made of a non-magnetic material as nylon. The tubular space between the coil and housing is filled with powdered ferrite 5. This ferrite filler may be impregnated with a binder or it may be sealed into the space by seal 6. The ferrite 5 which forms a tube around the coil shields the coil electromagnetically and increases the inductance of the coil. Both the shielding and increased inductance enhance the performance of the sensor. The housing 3 is inserted into ring 4. Ring 4 is made of metal and may be a section of the valve actuator housing. The ring 4 acts to shield the coil electromagnetically. Position of shaft 8 in axial relation to the sensor coil assembly causes a change in inductance, and inductive resistance of coil 1. Shaft 8 is made of magnetic steel. Region 9 on shaft 8 is copper plated. Region 10 on shaft 8 is not plated. The sensor determines the position of the transition 11 between the plated area 9 and the unplated area 10.

Fig 2 shows dimensions of the sensor shown in Fig 1. Dimensions have a bearing on the inductance and resistance of the coil and hence on performance of the sensor.

There is a factor, Q, called the quality factor of the coil that effects the performance of this circuit.

$$Q = 2 \pi F L / R$$

Where: F = operating frequency of the coil in Hertz  
L = inductance of the coil in Henry's  
R = resistance of the coil in ohms

It is desirable to have a value of Q of 100 or more for many applications. The gauge of the wire, the number of turns of wire in the coil and the physical size of the coil all influence both L and R in the above equation. Larger wire lowers R. Longer length of wire raises R. Larger wire raises L. Larger diameter of the coil raises L. More turns of wire raises L and raises R as more length of wire is used. Also, shielding on the coil has an influence on its inductance and the operating frequency.

Fig 3 shows an alternate to the design of Fig 1 and Fig 2. In Fig 3 the shaft 8 has a region 9 on its end that interacts with the field produced by the sensor coil to produce variability in output. In this case the relative position of the end 11 of region 9 is determined. The region 9 may be a copper plated region of the shaft. Region 9 may also be a stainless steel region of the shaft, either magnetic or non-magnetic that is added to the shaft or is in fact the shaft material in total. A sensor of high resolution may be made if the region 9 is ferrite. The ferrite may be a sintered part or it may be made of powdered ferrite held together in a matrix by a binder.

#### Circuit

Fig 4 shows the sensor oscillator circuit used with this invention. The circuit has two main functional blocks, a regulated power supply and a tuned oscillator circuit.

The on board regulated +5VDC supply (U1) is used to power the oscillator functional block.

The tuned oscillator circuit is comprised of an amplifier (U2) and two reactive components, an inductor L1 and a capacitor C4. The frequency of the oscillator is:

$$F = \frac{1}{2 \pi \sqrt{LC}}$$

The amplifier U2 shown in Figure 1 is a high speed CMOS hex inverter. The resistor R2 is used to bias the input of the amplifier to compensate for the leakage current. The resistor R3 and capacitor C3 provide the feedback path. A transistor amplifier or operational amp will also work in place of hex inverter U2. The circuit shown in Figure 4 has sine wave output (J1-2). The inductor L1 is the coil in the sensors described here.

In the circuit described here a coil and a capacitor are used in series. Change in reactance of L1 is sensed by U2 through the feedback path (Fig 4). This causes the output of the circuit to vary with reactance of the coil. With the circuit of Fig 4 there are four variables, frequency of oscillation, inductance of L1, output voltage, and inductor resistance of L1. The circuit has output over a range dictated by the turns of the coil L1, capacitance of the capacitor C4 and permeability of the flux path created by L1 intersected by whatever objects might be in that flux path. The change in reactance of L1 amplified by U2 is output of the circuit that indicates the position of a movable object that influences the reactance of L1.

There are two ways that output can change with this circuit. One is when the inductance of the coil L1 changes, then frequency at J1-2 will change. The other is when the inductor resistance of L1 changes, this also influences frequency of oscillation.

Fig 5 and Fig 6 depict output circuitry for use with the circuit of Fig 4. This is a frequency to voltage conversion circuit. Output in VDC is at J2-2.

Fig 7 is a block diagram of a circuit for digital output from the circuit of Fig 4. In the block diagram the block marked sensor is the circuit of Fig 4. The oscillator is a free running oscillator of high frequency relative to the position sensor oscillator. The free running oscillator sources the input to the gate control logic. The sensor has a frequency output dependent on the position of the sensor actuator. The sensor sources the enable function to the gate control logic. The gate control passes the oscillator clock to the counter when the enable function is true. The position sensor also sources a timing status to the controller. The counter records the oscillator clock for a given window. The window is determined by the position sensor frequency. At the completion of a count window the gate control logic stops the clock to the counter. The controller receives status that a count window is complete. The controller reads the counter, resets the count for the next cycle and provides an output dependent on the count data.

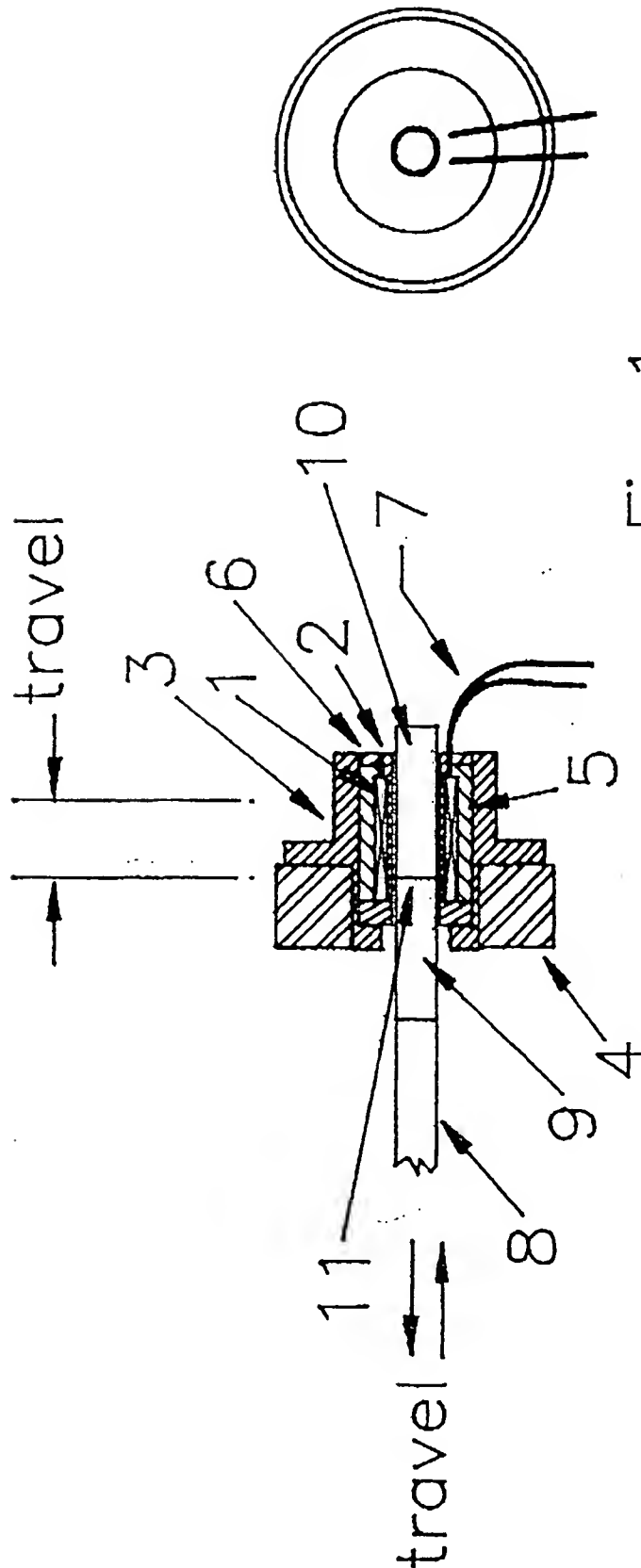


Fig 1

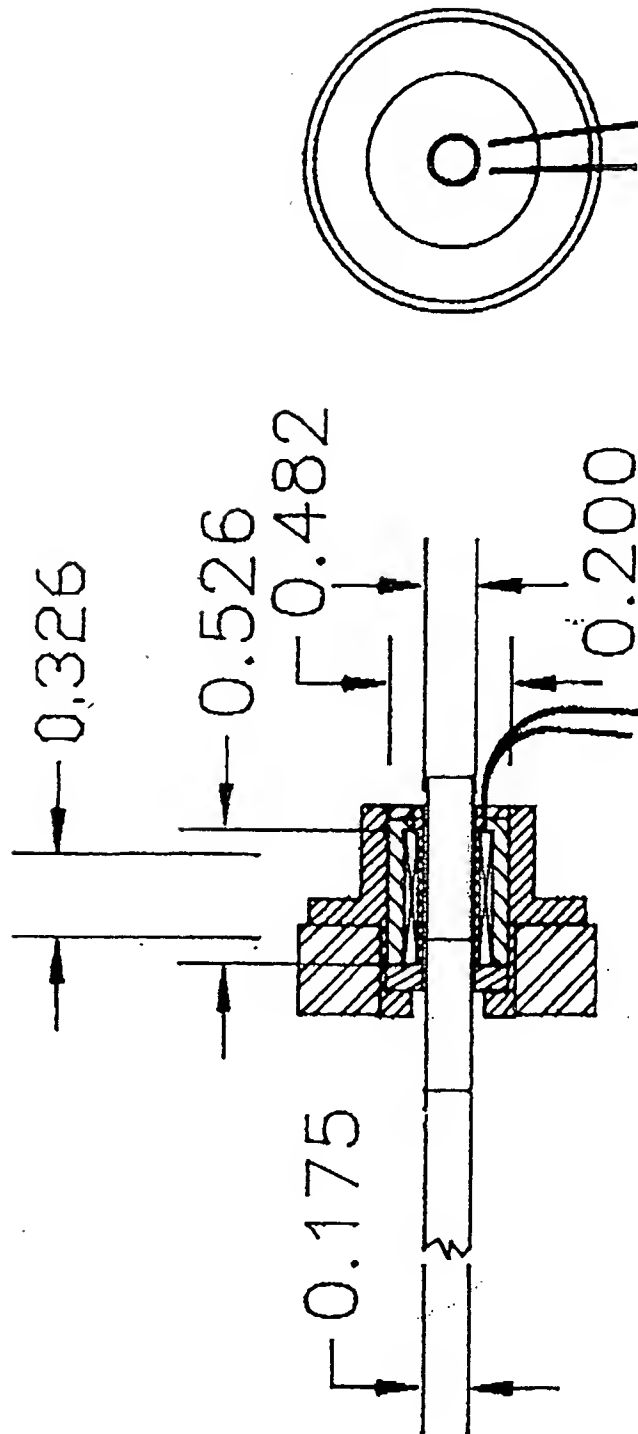


Fig 2

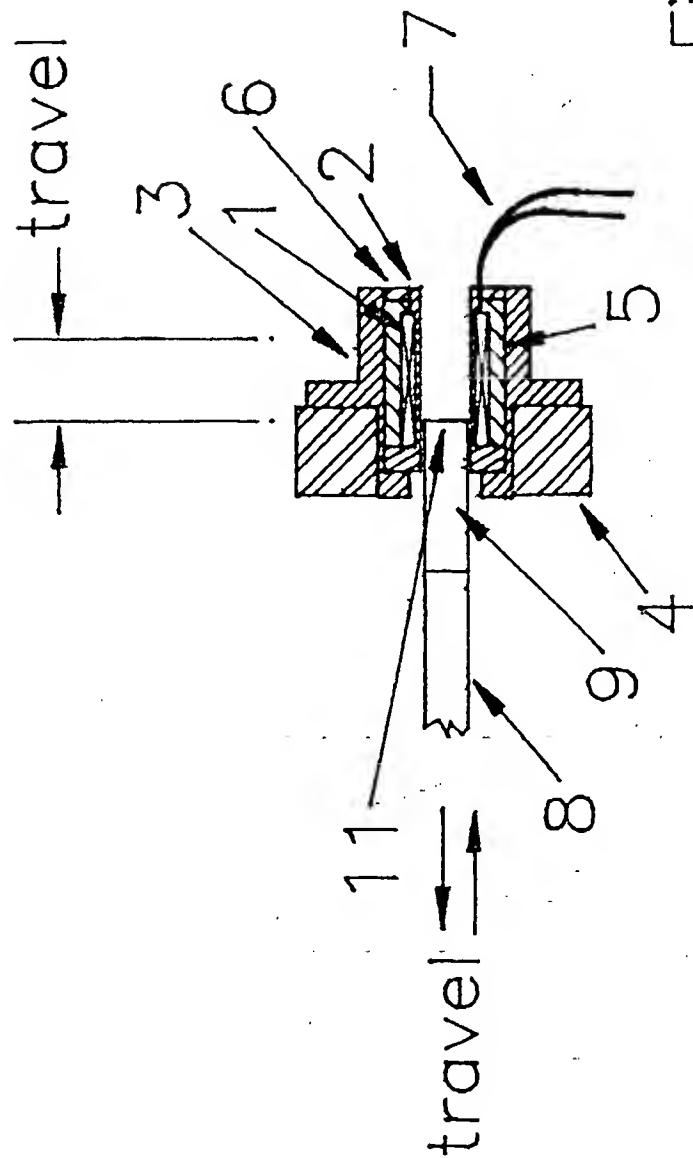
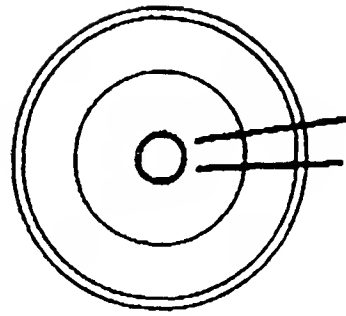
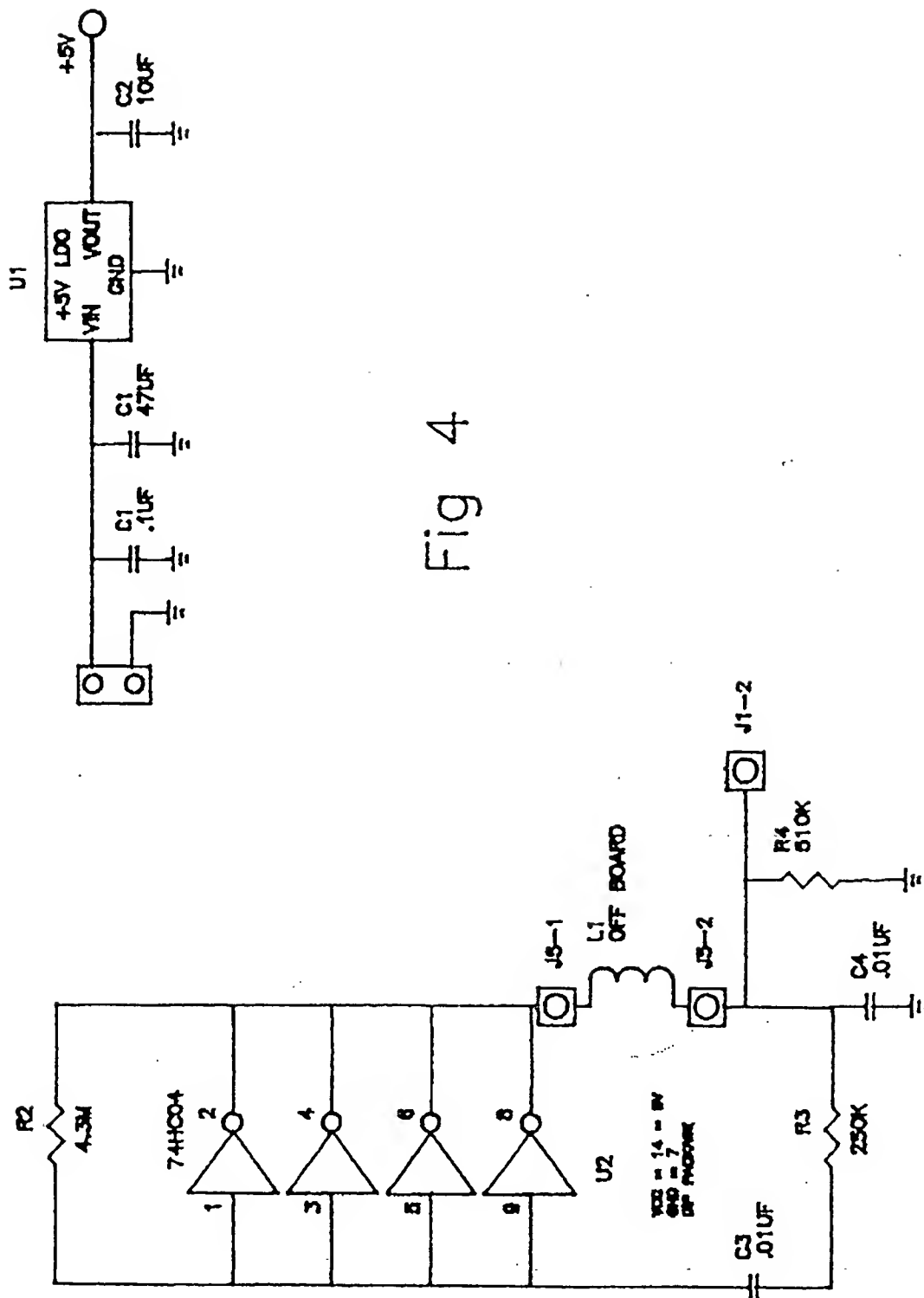


Fig 3





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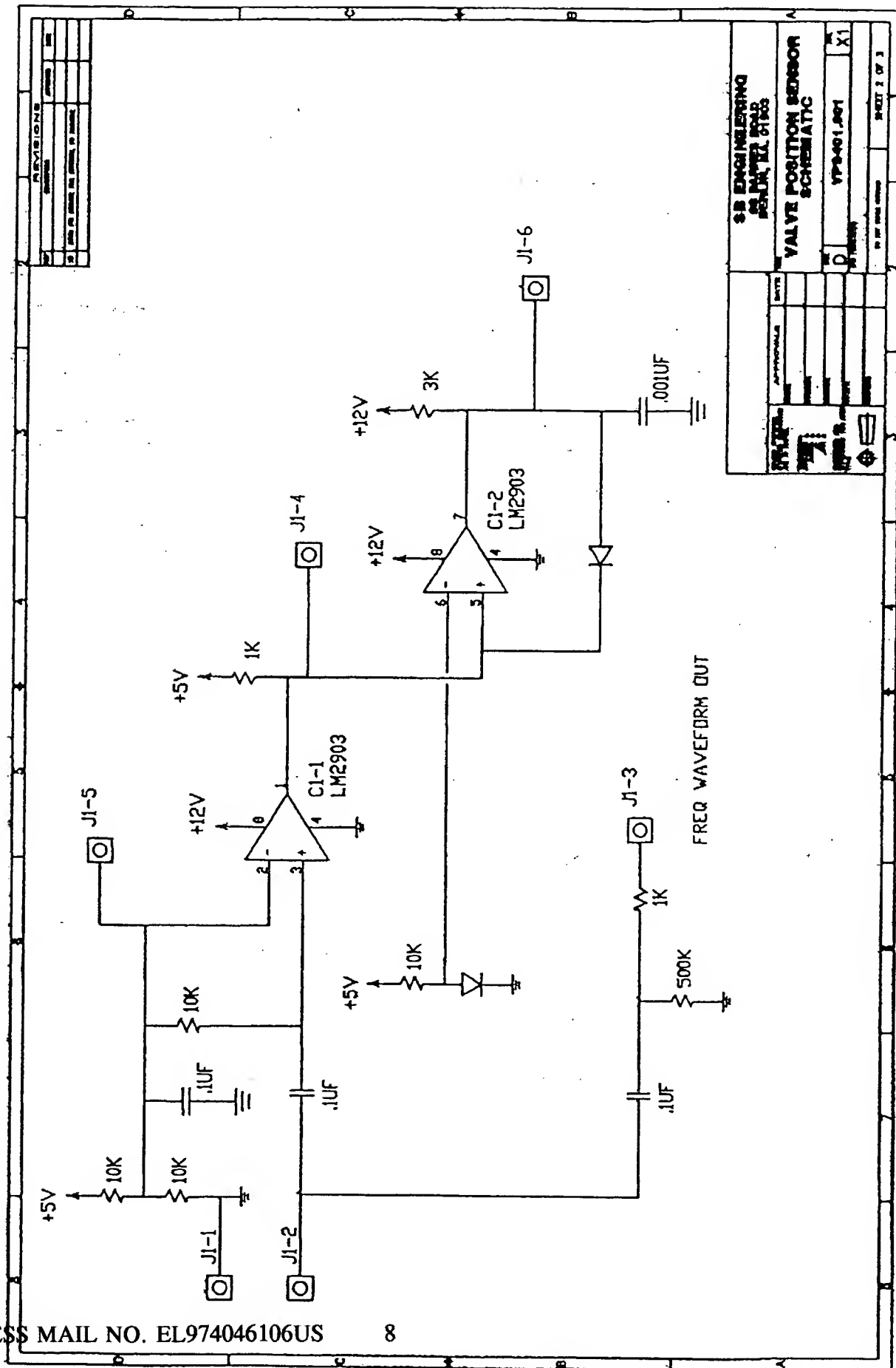


Fig 6

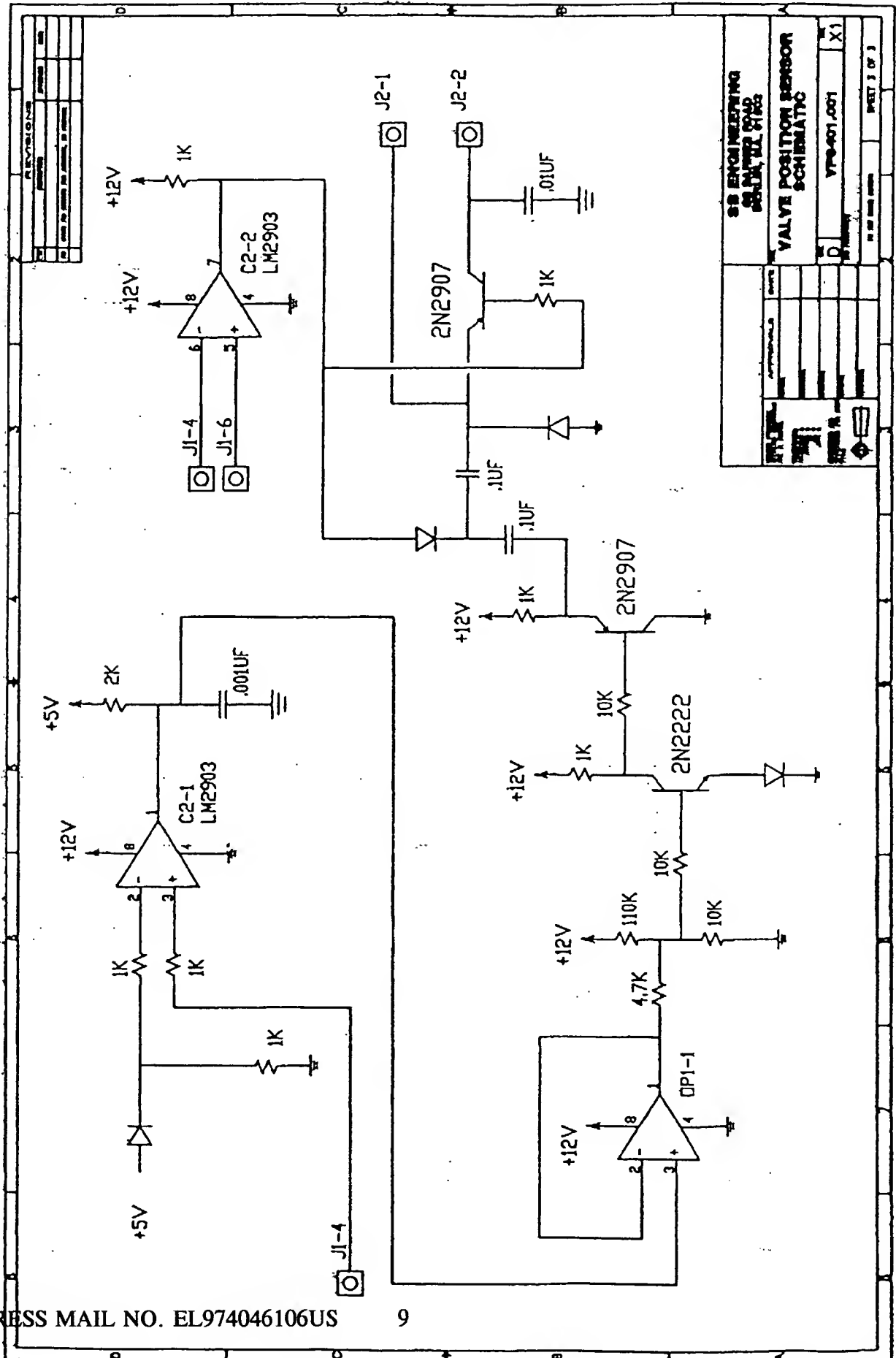
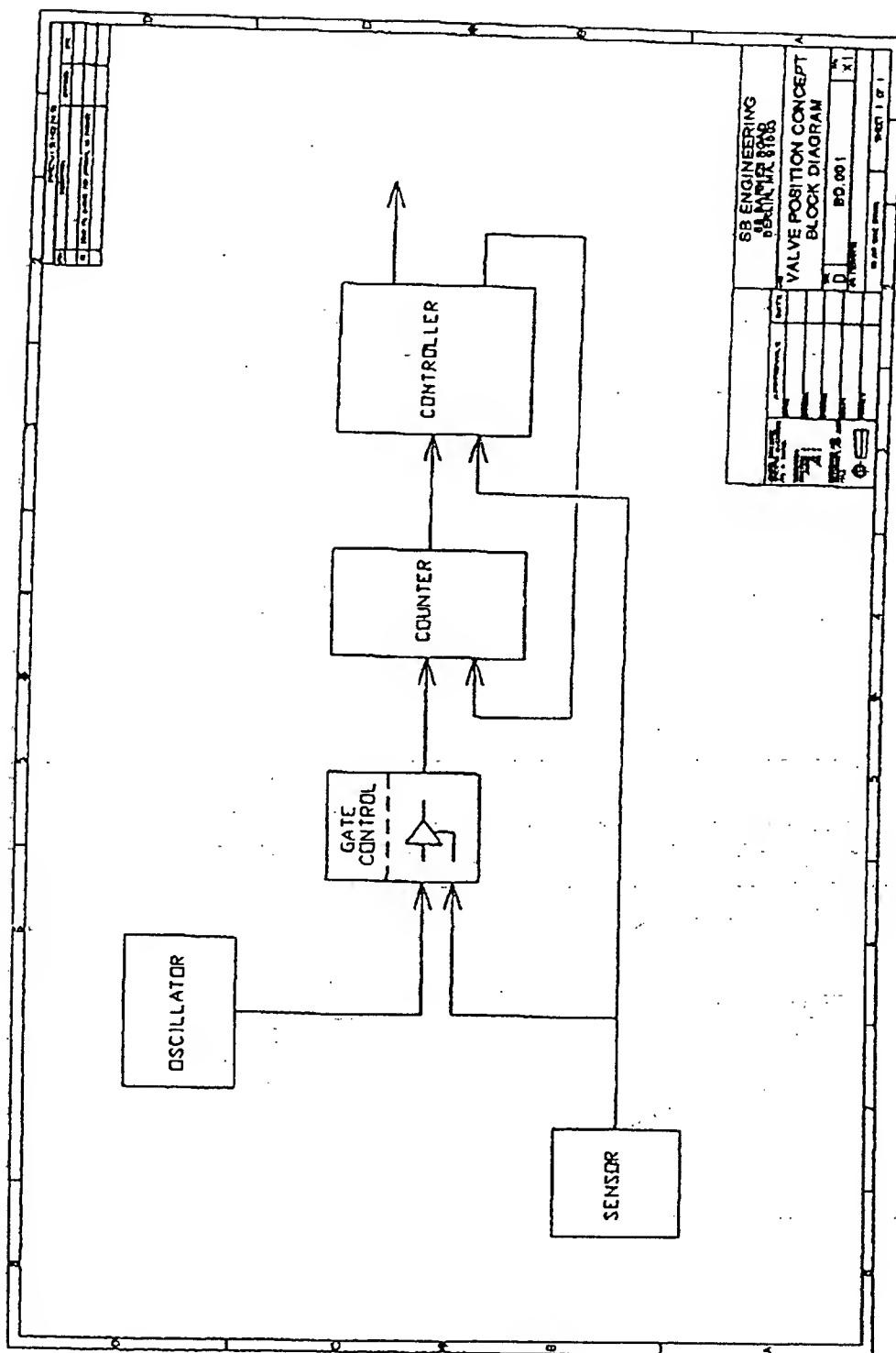


Fig 7



## Linear position sensors and circuit

### Abstract

Here are disclosed embodiments of non-contact linear position sensors and a circuit for operating the sensors. Movement of an metal or ferrite object in the electromagnetic field produced by a sensor coil causes a change in the coil's reactance. A tuned circuit produces an electrical output that varies with the reactance of the coil.

### Background

Linear non-contact position sensors are well known in the art. They suffer from complexity in their designs with resulting high cost for production. It is an object of this invention to provide a technology for a linear position sensor that provides accuracy, durability and low cost.

### Description

#### Circuit

Fig. 1 shows the position sensor circuit. The circuit has two main functional blocks, a regulated power supply and a tuned oscillator circuit.

The function of the regulated power supply is to allow the device to work on an input voltage of 8 – 50VDC. The positive voltage is applied to pin 3 of connector CT1 and ground (return) is applied to pin 1. An on board regulated +5VDC supply (U1) is used to power the oscillator functional block. This voltage regulator has a maximum input voltage of +16VDC. The transistor Q1 with the base voltage limited to 15VDC via the zener diode D1, keeps the input voltage to U1 below the maximum tolerance.

The tuned oscillator circuit is comprised of an amplifier (U2) and two reactive components, an inductor L1 and a capacitor C4. The frequency of the oscillator is:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The amplifier U2 shown in Figure 1 is a high speed CMOS hex inverter. The resistor R2 is used to bias the input of the amplifier to compensate for the leakage current. The resistor R3 and capacitor C3 provide the feedback path. A transistor amplifier or

operational amp will also work in place of hex inverter U2. The circuit shown in Figure 1 has two output signals, a sine wave (CT1 pin 2) and a DC voltage value (CT1 pin 4). The diode D2 and capacitor C5 rectify the sine wave output to a DC voltage value. The transistor Q2 is used to add some drive current to the DC voltage output signal. The inductor L1 is the coil in the sensors described here.

With circuits for prior art proximity sensors a coil and capacitor are used in parallel and tuned to give a strong signal at a particular frequency. In this way the prior art device is tuned to sense an object at a particular distance. In the circuit described here the coil and capacitor are used in series. This causes the output frequency and voltage to vary with reactance of the coil. Thus a more linear output signal is produced that is more appropriate for sensing an object over a range of distances.

#### Sensor

Fig 2 shows one embodiment of a sensor of the present invention. In this design a coil (L1 in the circuit of Fig 1) of conducting wire (for example 200 turns of 24 gauge copper wire) is wound on a plastic bobbin of the dimensions shown. A printed circuit board (PCB) with the circuit of Fig 1 is attached to the coil so that the wire connection from the coil to the circuit is short. Alternately the circuit can be placed in a remote location. However, if the circuit is in a remote location the wire connection from the coil to the circuit should be a coaxial cable. An armature, made of steel, resides in the axial hole through the center of the coil. Axial movement of the armature in relation to the coil causes change in output of the circuit. A sensor constructed to these specifications has voltage output of the trace designated "steel 1" in Fig 5. It should be noted that other dimensions for the coil including the use of a different number of turns of a different gauge wire, a different length and a different inside diameter are within the scope of this invention. Also an armature may be used that is made of a different metal.

An example of a different physical size for the sensor is shown in Fig 3. This sensor also has 200 turns of 24 gauge wire. Its output is shown as "steel 2" on Fig 5. It is also noted that the armature need not have a round cross section and the coil could be wound with a shape other than circular in section.

A sensor as depicted in Fig 2 and Fig 3 when used with a steel armature has output resolution greatest when measured by voltage change. This device is accurate, durable and inexpensive. However, the output of the device with a steel armature is affected by stray capacitance and by interference by metal objects that may move into the field surrounding the coil that is produced by the coil. This interference may cause the output reading to deviate from the reading without interference by as much as 5%.

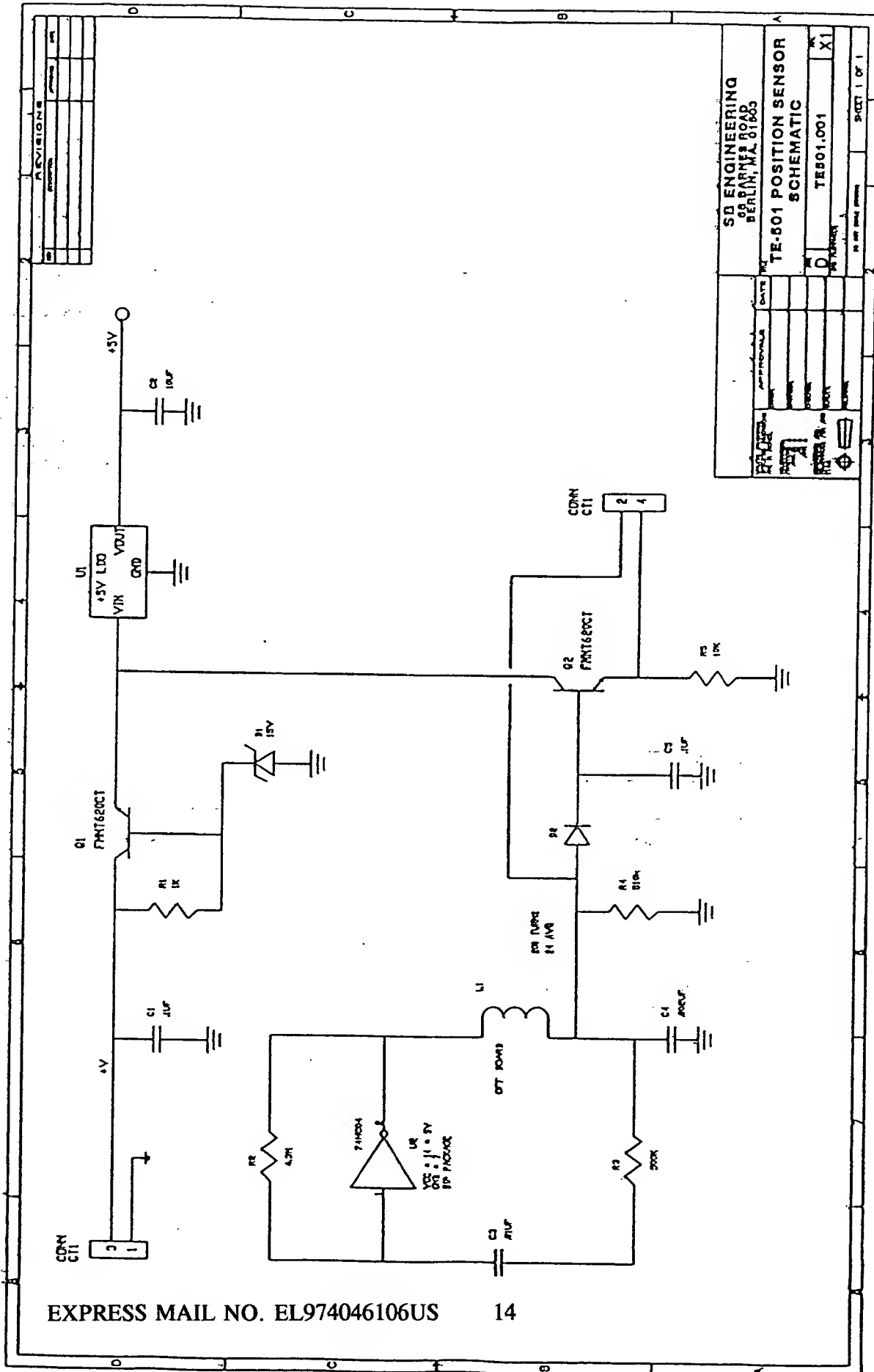
#### Reduction of effect of interference

The steel armature may be replaced with an armature made from ferrite. With a steel armature the interaction of the field with the metal of the armature causes eddy currents in the armature that interfere with propagation of the field. Hence voltage output of the

circuit decreases as the armature is placed farther into the field within the coil geometry. (Fig 5) Ferrite materials have high magnetic permeability as well as being easily magnetized and demagnetized. When a armature made of ferrite is introduced into the field inside the coil the material in the armature couples with the field, resistance to propagation of the field is lowered and the voltage output of the circuit is increased. This output voltage is shown as "ferrite" in Fig 5. With the ferrite core in the sensor of Fig 2 voltage output is not effected by the stray capacitance used in the test with the steel armature while the effect of a metal object in the external field is reduced to 2% of range.

With the steel armature in the sensor described above and shown in Fig 2 output frequency variation over the range shown in Fig 5 is 3 kHz starting at 100 kHz and going to 97 kHz. This is shown as "steel" in Fig 6. With the same coil with a ferrite armature frequency varies from 97 kHz to 52 kHz for a total of 45 kHz over the same measuring range, while output voltage varies from 7.5 to 10.1 volts. The frequency variation is shown as "ferrite" in Fig 6 and the voltage variation as "ferrite" in Fig 5. With a ferrite armature, better resolution is attained by using frequency for output. Meanwhile, the same external forces that caused a voltage change of 5% of range in the sensor with a steel armature will cause a frequency change of 0.1% of range in the sensor with a ferrite armature. By using an armature made of ferrite a sensor can be made that is accurate, durable, immune to outside influences and low cost.

Another embodiment of the present invention is shown in Fig 4. For references and to show operational similarities to the design of Fig 2 a bobbin and coil with the same size and shape as the bobbin and coil in Fig 2 is used. Also, 200 turns of 24 gauge wire are used. Here a stationary yoke is included in the design. The yoke is made of ferrite in two "L" shaped pieces that are butted together inside the coil. The two legs of the two L's are perpendicular to the centerline of the coil. The ferrite core couples to the electromagnet field produced by the coil and concentrates it between it open legs. This sensor uses a steel armature. The armature moves parallel to the axis of the coil in the field between the two ends on the ferrite yoke. Output in volts is shown as "steel 3" in Fig 5. With this design the sensor can be made as a solid construction with no cavity for foreign matter to collect. The armature can be a section of a machine component. Also, effect of stray capacitance on the output of the sensor is small. Again, as with the design of Fig 2, other dimensions for the coil including the use of a different number of turns of a different gauge wire, a different length and a different inside diameter are within the scope of this invention. Also, the sensor may be made without a bobbin. A one piece yoke may be used, electrical insulation placed on the yoke and the coil wound on the yoke with insulation.



# FIGURE 1

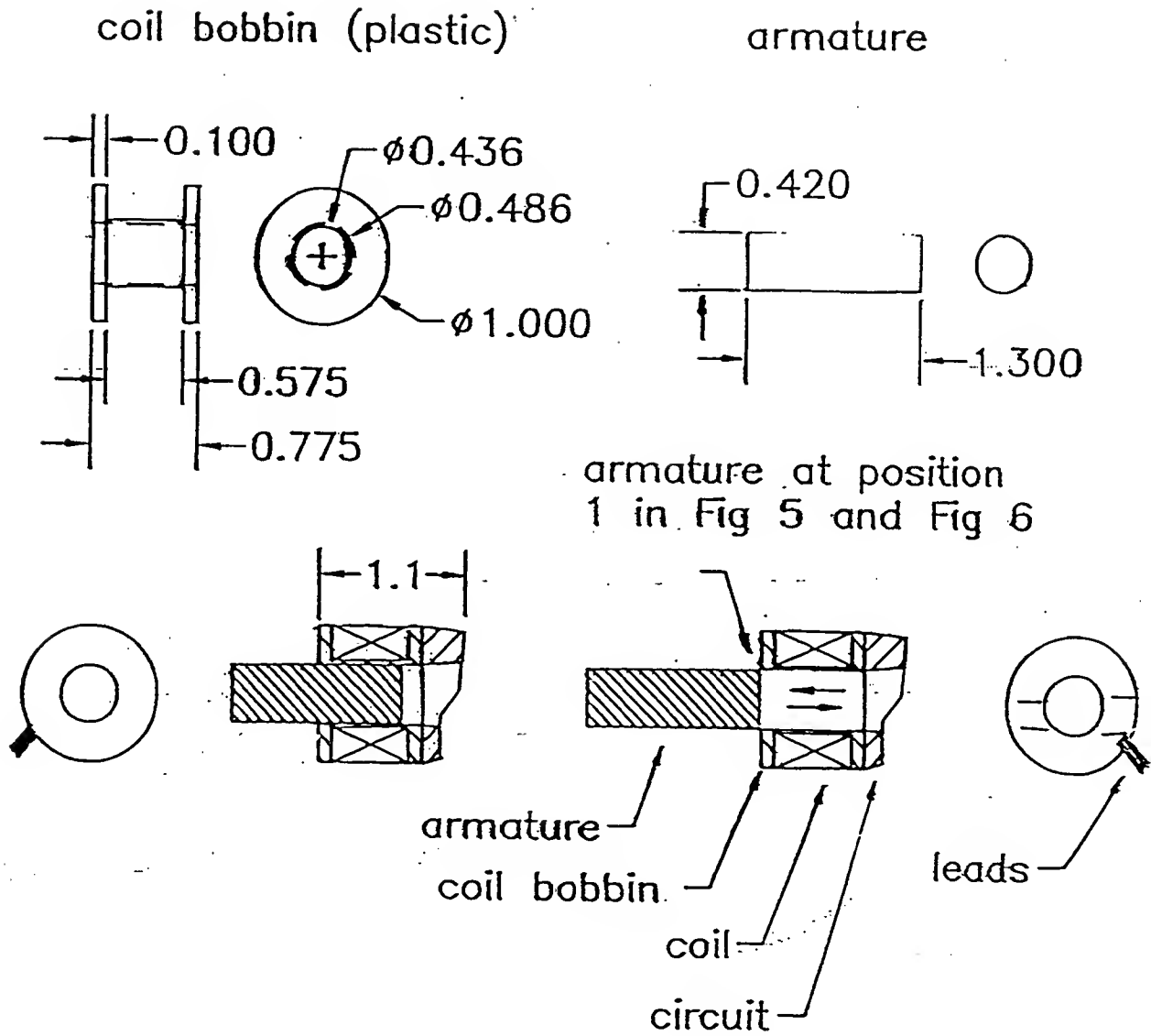


Fig 2

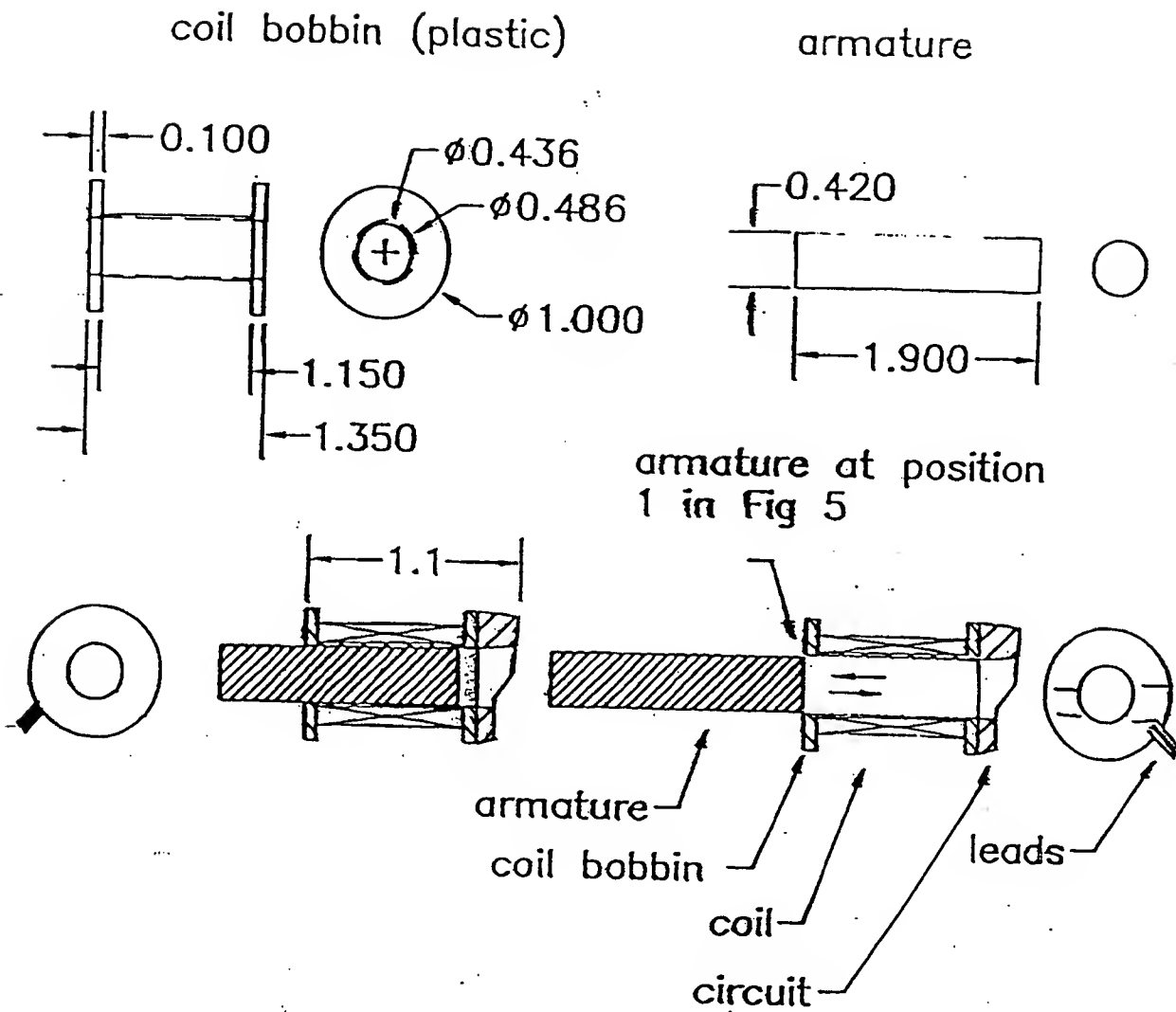


Fig 3

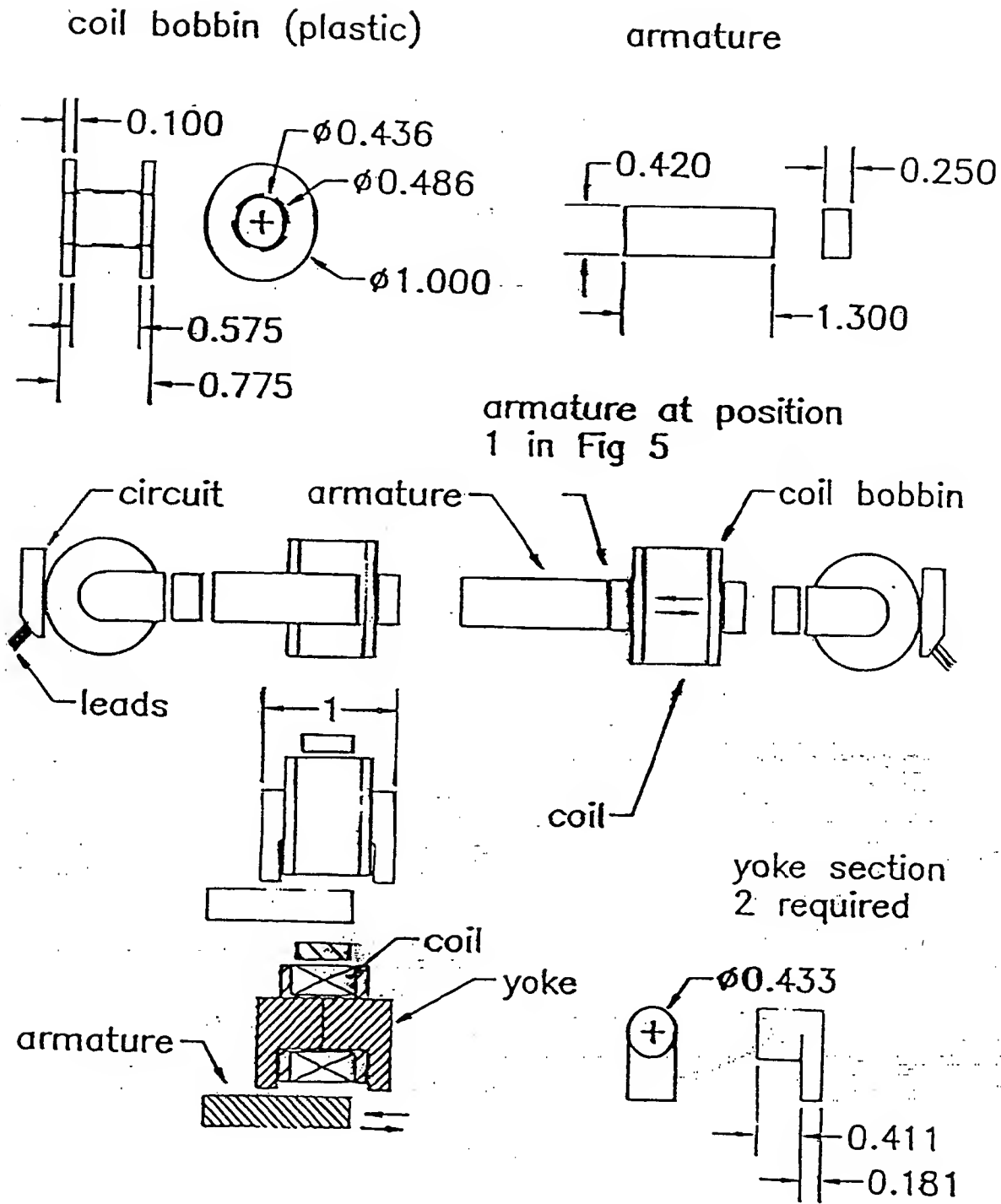


Fig 4

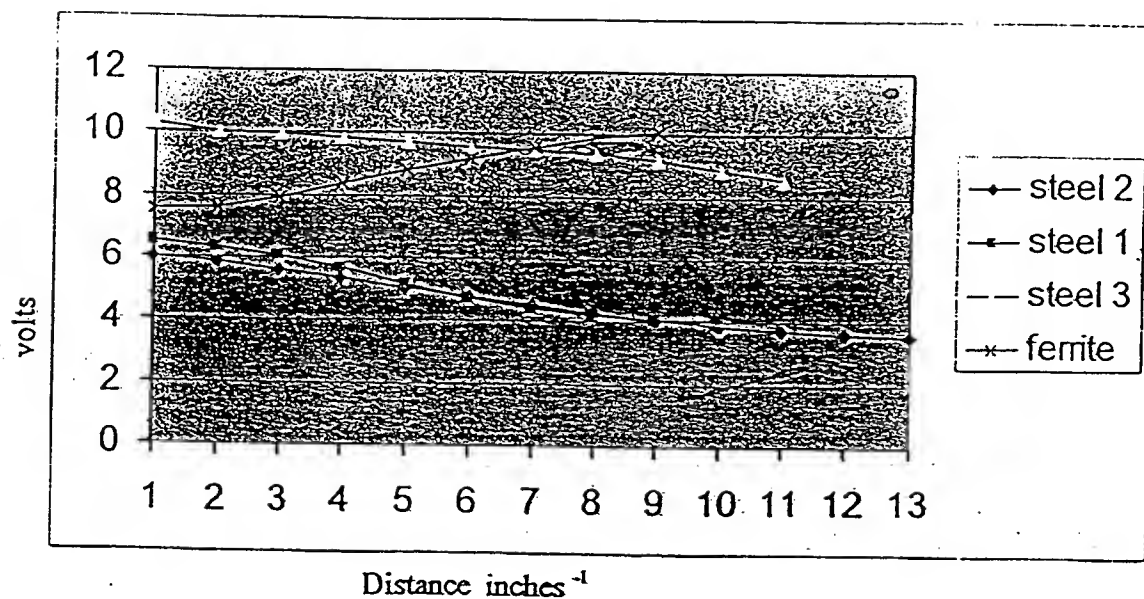


Fig 5

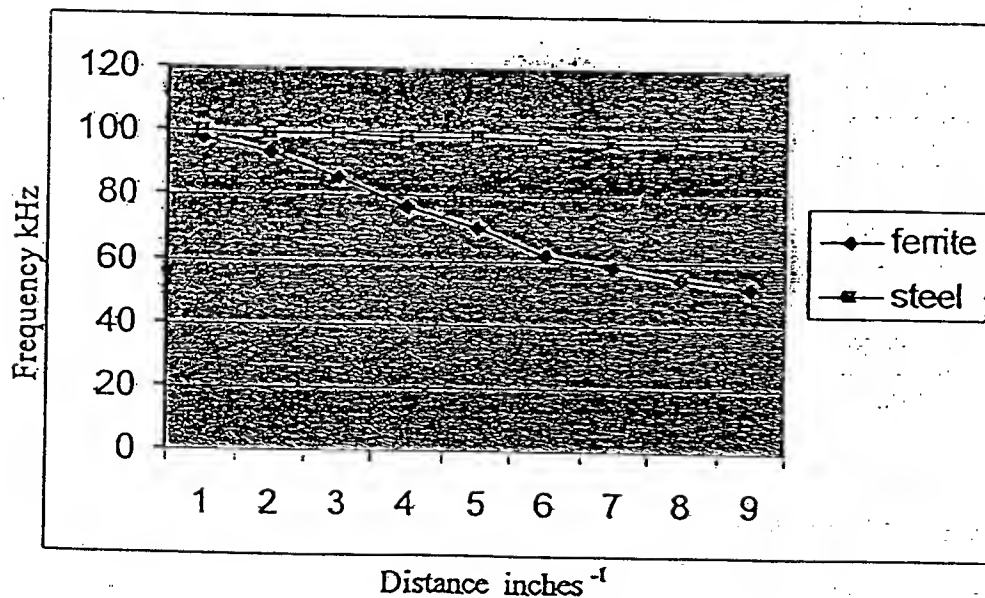


Fig 6

## Linear position and motion sensors and circuit

### Reference

U.S. Patent 2,408,524

U.S. Patent 2,461,210

U.S. Patent 5,767,672

U.S. Patent 6,335,619

### Abstract

Here are disclosed embodiments of non-contact position and motion sensors and a circuit for operating the sensors. Movement of a metal or ferrite object in the electromagnetic field produced by a sensor coil causes a change in the coil's reactance. A tuned circuit produces an electrical output that varies with the reactance of the coil.

### Background

Linear non-contact position sensors are well known in the art. One type is the linear variable differential transformer (LVDT). They are comprised of a primary and two secondary windings that are variably coupled by a magnetic core. The movement of the core in relation to the winding produces variable output from the secondary windings. The variable output is used to indicate position of the core in relation to the device. The LVDT is accurate but they suffer from complexity in their designs with resulting high cost for production. Another type of position sensor is the inductive proximity sensor (IPS). The IPS has a single electrical coil mounted in a core of magnetic material. The coil and core with associated circuit produce an electromagnetic field that is projected from the core. Metal objects introduced into that field produce a change in the field that is detected by the circuit. The IPS of the prior art is useful for determining the presence or absence of an object at a specific location in relation to the sensor with moderate accuracy. They are low in cost but are not good at sensing movement or determining location with accuracy. It is an object of this invention to disclose a technology for a linear position sensor that provides accuracy, durability and low cost. It is also an object of this invention to disclose an apparatus that is appropriate for measuring amplitude and frequency of vibration and amplitude of acceleration.

### Material definition

In this paper components that are made of "ferrite" are discussed. There are many varieties of ferrite in existence. There are two classes of ferrite that have application in the art. One class of ferrites are called "soft ferrites". Soft ferrites are materials of high magnetic permeability that are easily magnetized and demagnetized. These materials are appropriate for magnetics in high frequency applications. The other class of ferrites are called "hard ferrites". Hard ferrites are used for permanent magnets. What is meant by ferrite in this paper is soft ferrite.

Throughout this paper and in all associated drawings the dimensions are in inches.

#### Description – Circuit

With the prior art IPS a coil and a capacitor are used to generate an oscillating electromagnetic field which is projected by the sensor. With circuits for prior art proximity sensors the coil and capacitor are used in parallel and tuned to resonate at a particular frequency. When a metal object enters that field eddy currents are created in the object by the field created by the sensor. The eddy currents cause an increase in inductor resistance. That change causes a decrease in oscillator voltage. This change in voltage is used for output. There is no feedback path from the oscillator to an amplifier with the result that this device is less sensitive or accurate than the devices disclosed here.

Fig 1 shows the sensor circuit of the present invention. The circuit has two main functional blocks, a regulated power supply and a tuned oscillator circuit.

The function of the regulated power supply is to allow the device to work on an input voltage of 8 – 50VDC. The positive voltage is applied to pin 3 of connector CT1 and ground (return) is applied to pin 1. An on board regulated +5VDC supply (U1) is used to power the oscillator functional block. This voltage regulator has a maximum input voltage of +16VDC. The transistor Q1 with the base voltage limited to 15VDC via the zener diode D1, keeps the input voltage to U1 below the maximum tolerance.

The tuned oscillator circuit is comprised of an amplifier (U2) and two reactive components, an inductor L1 and a capacitor C4. The frequency of the oscillator is:

$$F = \frac{1}{2 \pi \sqrt{LC}}$$

The amplifier U2 shown in Figure 1 is a high speed CMOS hex inverter. The resistor R2 is used to bias the input of the amplifier to compensate for the leakage current. The resistor R3 and capacitor C3 provide the feedback path. A transistor amplifier or operational amp will also work in place of hex inverter U2. The circuit shown in Figure 1 has two output signals, a sine wave (CT1 pin 2) and a DC voltage value (CT1 pin 4). The diode D2 and capacitor C5 rectify the sine wave output to a DC voltage value. The

transistor Q2 is used to add some drive current to the DC voltage output signal. The inductor L1 is the coil in the sensors described here.

In the circuit described here a coil and a capacitor are used in series. As with the IPS, an electromagnetic field is produced, and again the position of a metal object is sensed in that electromagnetic field by change in the reactance of the coil. Change in reactance of L1 is sensed by U2 through the feedback path (Fig 1). This causes the output of the circuit to vary with reactance of the coil. With the circuit of Fig 1 there are four variables, frequency of oscillation, inductance of L1, output voltage, and inductor resistance of L1. The circuit has output over a range dictated by the turns of the coil L1, capacitance of the capacitor C4 and permeability of the flux path created by L1 intersected by whatever objects might be in that flux path. The change in reactance of L1 amplified by U2 is output of the circuit that indicates the position of a movable object that influences the reactance of L1.

There are two ways that output can change with this circuit. One is when the inductance of the coil L1 changes, then frequency at CT1 pin 2 will change. The other is when the inductor resistance of L1 changes, then voltage at CT1 pin 4 will change. When an oscillating electromagnetic field is produced by L1 this field nominally surrounds L1 on its inside and outside. Objects of varying size and physical composition will have effect in varying degrees on one or both of these output parameters. The circuit and sensors here described exploit these changes.

#### Position Sensors

Fig 2 shows one embodiment of a sensor of the present invention. In all the examples of sensors presented in this paper the sensor coil is coil L1 in Fig 1. In Fig 2 the coil is made of 200 turns of 24 gauge copper wire wound on a plastic bobbin of the dimensions shown. The voltage through the coil is of the magnitude of 5 to 10 volts. The number of turns of wire in the coil in conjunction with the capacitance of capacitor C4 are determined by the intended frequency of operation. The gauge of the wire, the number of turns in the coil, and the capacitance of C4 can all be varied to produce devices that are useful for a particular application. The gauge of the wire used may be primarily determined by manufacturing convenience and economy.

A printed circuit board (PCB) with the circuit of Fig 1 is attached to the coil so that the wire connection from the coil to the circuit is short. Alternately the circuit can be placed in a remote location. However, if the circuit is in a remote location the wire connection from the coil to the circuit should be a coaxial cable. This relationship of the PCB with the circuit of Fig 1 and the sensor coil holds true for all the sensors described in this paper. An armature, made of steel, resides in the axial hole through the center of the coil. Axial movement of the armature in relation to the coil causes change in output of the circuit. A sensor constructed to these specifications has voltage output of the trace designated "steel 1" in Fig 5. It should be noted that other dimensions for the coil including the use of a different number of turns of a different gauge wire, a different length and a different inside diameter are within the scope of this invention. In this paper

"steel" indicates alloy 1018 steel. Other magnetic steel and iron alloys can be substituted for 1018 steel with similar or identical results. Also, an armature may be used that is made of non-magnetic metal. Aluminum, copper, copper alloys, and non-magnetic stainless steels can all be used. The output characteristics of the device when used with an armature made of a non-magnetic metal will vary from the output when the armature is made of steel. In general, output of a sensor when using a non-magnetic metal armature will have less resolution and sensitivity than with a magnetic metal armature.

An example of a different physical size for the sensor is shown in Fig 3. This sensor also has 200 turns of 24 gauge wire. Its output is shown as "steel 2" on Fig 5. It is also noted that the armature need not have a round cross section and the coil could be wound with a shape other than circular in section.

A sensor as depicted in Fig 2 and Fig 3 when used with a steel armature has output resolution greatest when measured by voltage change. This device is accurate, durable and inexpensive. However, the output of the device with a steel armature is affected by stray capacitance and by interference by metal objects that may move into the field surrounding the coil that is produced by the coil. This interference may cause the output reading to deviate by as much as 5% from what the reading would be if no interference were present.

#### Reduction of effect of interference

The steel armature may be replaced with an armature made from ferrite. With a steel armature the interaction of the field with the metal of the armature causes eddy currents in the armature that interfere with propagation of the field. Hence voltage output of the circuit decreases as the armature is placed farther into the field within the coil geometry. (Fig 5) Ferrite materials have high magnetic permeability as well as being easily magnetized and demagnetized and ferrite materials are non-conductors. When an armature made of ferrite is introduced into the field inside the coil the material in the armature couples with the field, resistance to propagation of the field is lowered and the voltage output of the circuit is increased. This output voltage is shown as, "ferrite" in Fig 5. With the ferrite core in the sensor of Fig 2 the effect of stray capacitance used in the test with the steel armature is reduced to a level below the measurement capability of the equipment used in the test. The effect of a metal object in the external field is reduced to 2% of the measured output range.

With the steel armature in the sensor described above and shown in Fig 2 output frequency variation over the range shown in Fig 5 is 3 kHz starting at 100 kHz and going to 97 kHz. This is shown as "steel" in Fig 6. With the same coil with a ferrite armature frequency varies from 97 kHz to 52 kHz for a total of 45 kHz over the same measuring range, while output voltage varies from 7.5 to 10.1 volts. The frequency variation is shown as "ferrite" in Fig 6 and the voltage variation as "ferrite" in Fig 5. With a ferrite armature, better resolution is attained by using frequency for output. Meanwhile, the same external forces that caused a voltage change of 5% of range in the sensor with a steel armature will cause a frequency change of 0.1% of range in the sensor with a ferrite

armature. By using an armature made of ferrite a sensor can be made that is accurate, durable, more immune to outside influences and low in cost.

Another embodiment of the present invention is shown in Fig 4. For references and to show operational similarities to the design of Fig 2 a bobbin and coil with the same size and shape as the bobbin and coil in Fig 2 is used. Also, 200 turns of 24 gauge wire are used. Here a stationary yoke is included in the design. The yoke is made of ferrite in two "L" shaped pieces that are butted together inside the coil. The two legs of the two L's are perpendicular to the centerline of the coil. The ferrite core couples to the electromagnet field produced by the coil and concentrates it between it's open legs. This sensor uses a steel armature. The armature moves parallel to the axis of the coil in the field between the two ends on the ferrite yoke. Output in volts is shown as "steel 3" in Fig 5. With this design the sensor can be made as a solid construction with no cavity for foreign matter to collect. The armature can be a section of a machine component. Also, effect of stray capacitance on the output of the sensor is small. Again, as with the design of Fig 2, other dimensions for the coil including the use of a different number of turns of a different gauge wire, a different length and a different inside diameter are within the scope of this invention. Also, the sensor may be made without a bobbin. A one piece yoke may be used, electrical insulation placed on the yoke and the coil wound on the yoke with insulation.

#### Improved resolution

An electromagnetic field is produced by the coil L1 in the circuit of the instant invention. That field is depicted in Fig 7. As shown in Fig. 7, the field is both inside the windings of the coil and outside of the windings. In the devices shown in Fig 2, 3, and 4 a component of the particular sensor is used to interact with that part of the field that resides inside of the coil.

Fig 8 and Fig 9 show sensors similar to the sensors in Fig 2 and Fig 3. In the sensors of Fig 8 and Fig 9 ferrite is used for the armature. By placing ferrite in that part of the field that resides outside of the coil performance of the device is improved. Fig 8 and Fig 9 show sensors that have ferrite in the field path outside of their coils. In Fig 8 the sensor coil, on its bobbin resides inside of a housing along with two shell sections. The shell sections, which are made of ferrite, provide a path of high magnetic permeability on the outside of the coil for the electromagnetic flux produced by the device. By lowering the relative distance that the flux path is in air to that distance that the flux path is in a high permeability material (ferrite) the resolution of the device is improved. The output of this device is shown as Ferrite 8 in Fig 10. The aluminum housing is a mechanical protection, a mounting mechanism, and also shields the sensor from influence of metal parts intruding into stray components of the field produced by the sensor. It is important that the inside diameter of the housing is spaced at some distance (for example 0.1 inches) from the coil. If it is spaced too close the aluminum of the housing will interfere with the flux path of the field and lower resolution.

Fig 9 shows a sensor of the type of Fig 8. With the sensor of Fig 9 the coil on its bobbin resides inside of a tubular shield made of ferrite. The output of this sensor is shown as Ferrite 9 in Fig 10. The shield, coil, and circuit of this sensor may be molded into a plastic part. The coils used in the devices shown in Fig 8 and Fig. 9 have 200 turns of 34 gauge wire.

As with the sensor shown in Fig 2 and Fig 3, the sensors shown in Fig 8 and Fig 9 may be used with metal armatures. In that case the output would be taken in volts. Use of a steel or other metal armature may be desirable for design considerations other than output resolution.. Ferrite has low mechanical strength and it may be desirable to have a stronger component for the armature. It may be desirable to eliminate the mechanical connection between the ferrite and the source of motion. For economy as well as strength considerations it may be desirable to have the armature as an extended portion of a machine component.

#### Actuator Outside of Coil

Fig 11 is a representation of a field generator of a type commonly used in inductive proximity sensors. It has a ferrite core that is a composite of three cylinders. The core has a cylindrical center section, a cylindrical rim that is concentric with the center section and a cylindrical base that connects the center and rim. This type of core is called a pot core in the art. In the space between the center section and rim resides an electrical coil. When this device is connected to an oscillating electric current a field is generated as depicted in Fig 11. If the circuit is the circuit depicted in Fig 1 the position and movement of a metal actuator can be determined when that actuator is in the field. If the actuator is moved in a plane parallel to the face of the pot core position of the actuator relative to the center of the pot core can be ascertained. Output of the device when a steel actuator moves across the face of the core in a plane parallel to the face of the core is depicted in Fig 14 as "pot core". The coil in this device has 200 turns of 24 gauge wire and uses the same bobbin as the devices shown in Fig 2 and Fig 4.

Fig 12 shows a device that projects a field from its face in a similar way to the device in Fig 11. That is, field flux lines connect the center and rim of the ferrite core of the device and these lines have an arc shape. With the device of Fig 12 a center portion of a ferrite core resides inside of a coil and another portion of the ferrite core is concentric to the center portion and resides outside of the coil. These two portions of the core are connected by a third portion of the core. But now instead of the center portion being cylindrical it has the shape of a rectangular prism. This core design is here called an oval core. With the pot core device the field generated is circular. With the oval core device the field generated is longer along the length of the center section. If the cross section of the device is uniform in direction CC in Fig 12 then the flux distribution will be uniform in the direction of the length, dimension 1.10 in Fig 12. With this device a metal actuator may move in a plane parallel to the face of the core. The position of the actuator's edge in the field is indicated by the output of the circuit. Since the flux distribution is linearized as compared to the flux of the pot-core device the output for this device is more linear. The output of this device with a steel target is shown as "oval core" in Fig 14.

Fig 13 shows a device with the same coil as the device in Fig 12, but the core in the device in Fig 13 has been truncated as compared to the core used in the oval core device. There is no ferrite around the ends of the coil. This device is here called an E core device. E shaped ferrite parts are common in the art. Since there is less material in the E core compared to the oval core the E core is less expensive. The output of the E core and oval core are practically identical, however because there is no ferrite around the ends of the coil the E core device is subject to output fluctuation caused by metal objects intruding into the field around the end of the device. The coils used in the devices shown in Fig 12 and Fig 13 have 200 turns of 34 gauge wire.

It may be desirable to have an actuator with a cylindrical cross section for use with a device like the one in Fig 13. Fig 15 shows a device designed to be used with a cylindrical actuator. Sensors of this type are more sensitive if the perpendicular distance between the faces of the core from which the electromagnetic field emanates and the face of the actuator that intersect that field are smaller. That is, the distance that the electromagnetic field travels in air from the core to the actuator is minimized. In the device shown in Fig 15 the cross section of the core has been made so that the distance that the field travels to the actuator in air is small when the actuator is interacting with the field. In effect, the legs of the "E" have been stretched to bring the legs into close proximity to the actuator. In this way accurate sensors can be made that will work with actuators that have shapes that are cylindrical, hexagonal, triangular, etc.

In the same way that other metals could be substituted for steel when making armatures for the devices of Fig 2, Fig 3, and Fig 4 other metals may be substituted for steel when making the actuators of Fig 11, Fig 12, Fig 13 and Fig 15.

#### Acceleration Sensors

The various devices described in this paper can be modified to be used as accelerometers. If the armature in the devices of Fig 2, 3, 4, 7, or 8 or the targets of the devices of Fig 11, 12, 13, or 15 are held at a fixed location within the field generated by the respective device by an elastic mechanism then deviation of output of the associated circuit will be an indication of a force of acceleration acting on that elastically held component. Said deviation can be calibrated to indicate force of acceleration or amplitude and frequency of vibration.

Fig 16 shows a device similar to the device depicted in Fig 9. The device in Fig 16 is adapted for use as an accelerometer. Since measuring length is not an issue when designing an accelerometer, the device can be made small. The part components of the device in Fig 15 are here described. The cylindrical armature is located in close sliding relationship inside the coil bobbin. A coil (in this case 200 turns of 34 gauge wire) is wound on the coil bobbin. The bobbin with coil is firmly attached inside of the ferrite shell. A radially wound spring has one end affixed to the outside of the shell and the other end affixed in the inside of the armature. The device may be directly mounted to a printed circuit board (PCB). This PCB may also mount the sensor circuit (Fig 1). Forces

of acceleration acting on the mechanism in the sensing direction cause the armature to move axially in the coil bobbin. The sensing direction is the axis of the coil. Movement of the armature in the assembly causes a change in output of the circuit. Sensitivity of the device to forces of acceleration can be adjusted by adjusting the mass of the armature. This can be done by changing the size of the armature, or by adding metal inside of the armature. The sensitivity can also be changed by changing the spring rate of the spring. This device has output in frequency and can be highly accurate.

In some applications for accelerometers it is not important that the device be able to detect and quantify forces over a range. It may be necessary only to detect a force of a given magnitude or greater, i.e. for sensing a shock. An example of an application where a device of this specification is appropriate is for deploying automotive air bags.

Fig 17 shows a device appropriate for sensing a shock. This device is similar to the device in Fig 16. Here the armature is made of steel and it may be welded to the spring. A characteristic of ferrite is it is brittle. This brittle character may cause a ferrite armature to fail under a severe strain situation. A steel armature obviates this problem. Having the steel armature in loose fitting relation to the coil bobbin reduces sensitivity, but reduces cost and increases durability. At most time the armature will not touch the bobbin so sliding wear is reduced. This device has output in volts.

#### Materials of Construction

There exist varieties of powdered iron and iron containing materials that have properties that make them usable substitutes for ferrite in the devices described here. Examples are iron powder, iron silicide, and ferrite loading powders. These materials are powders that can be mixed with various polymers (for example polyester) the resulting compositions can be formed into shapes and cured to create useful parts. It is the intention of this paper to disclose these materials as appropriate for manufacture of various components of the devices described here.

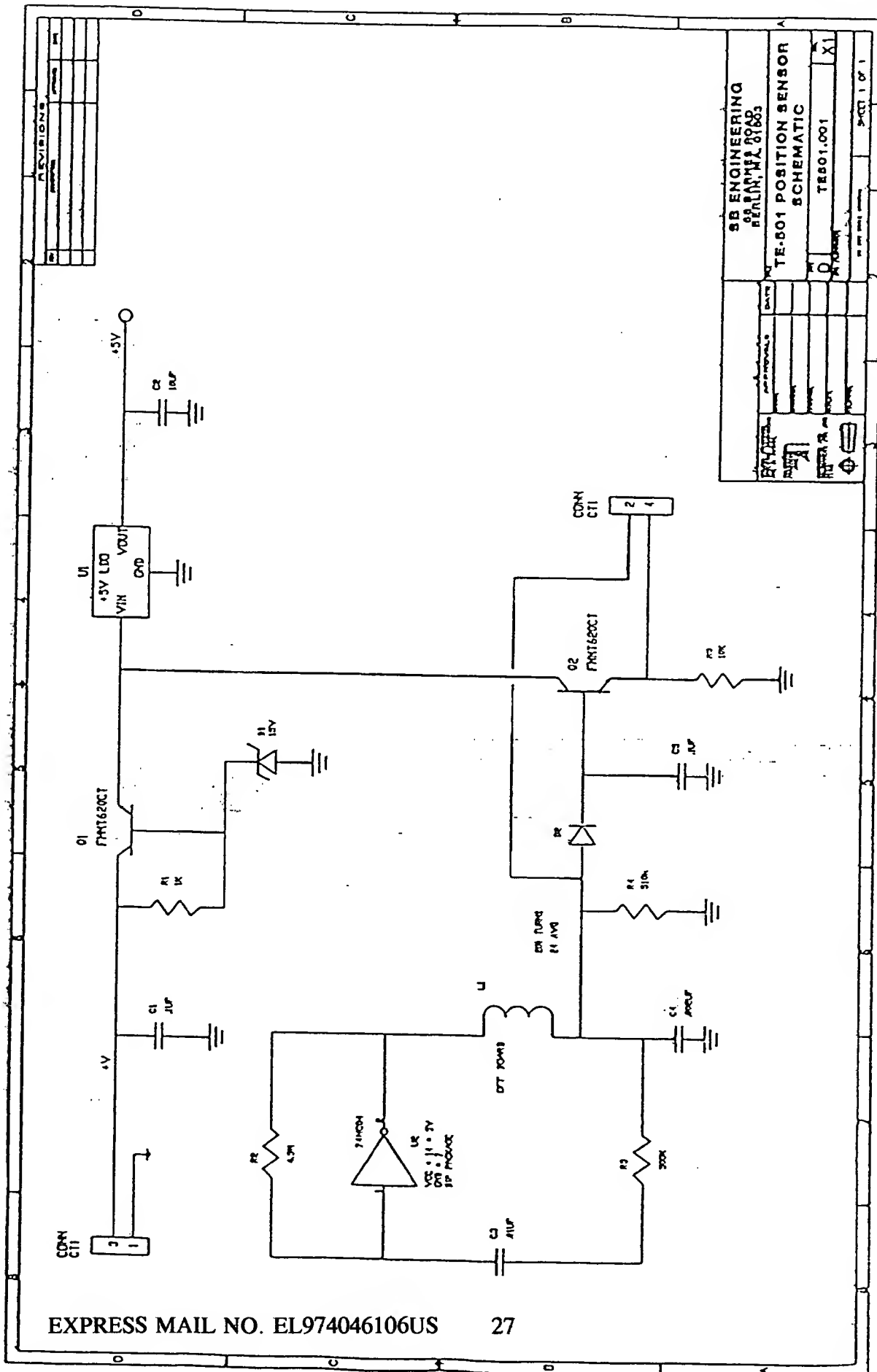


FIGURE 1

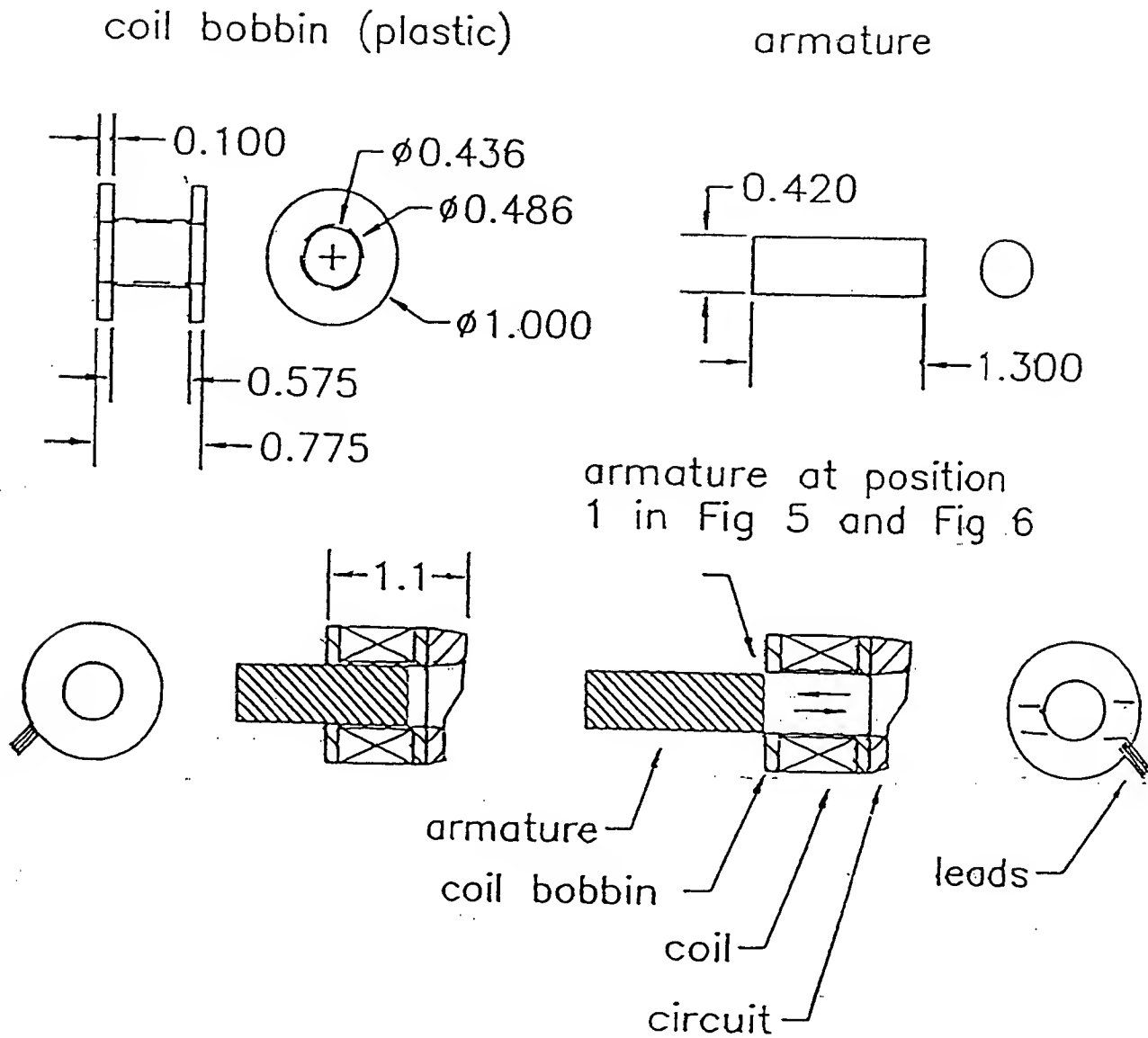


Fig 2

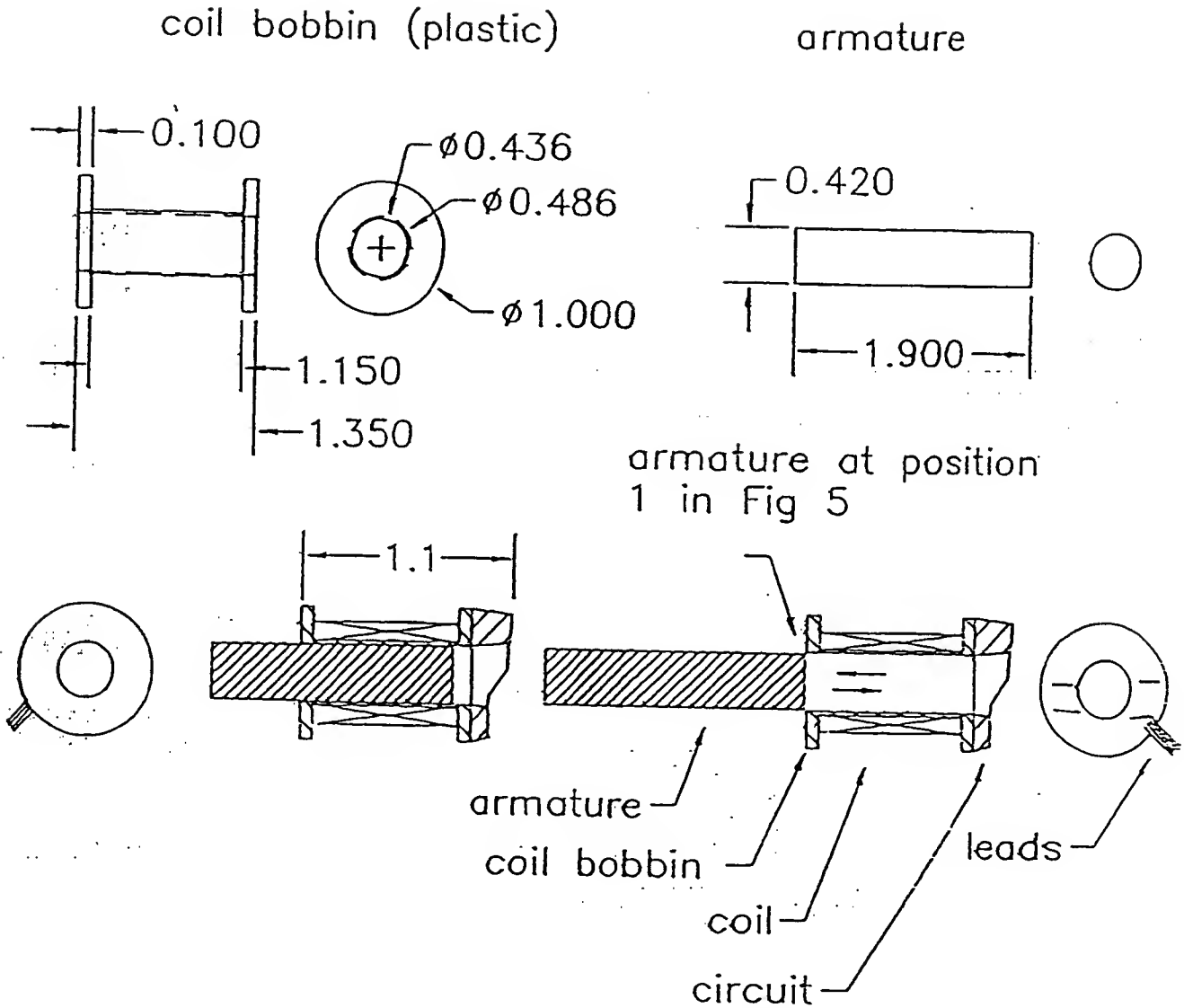


Fig 3

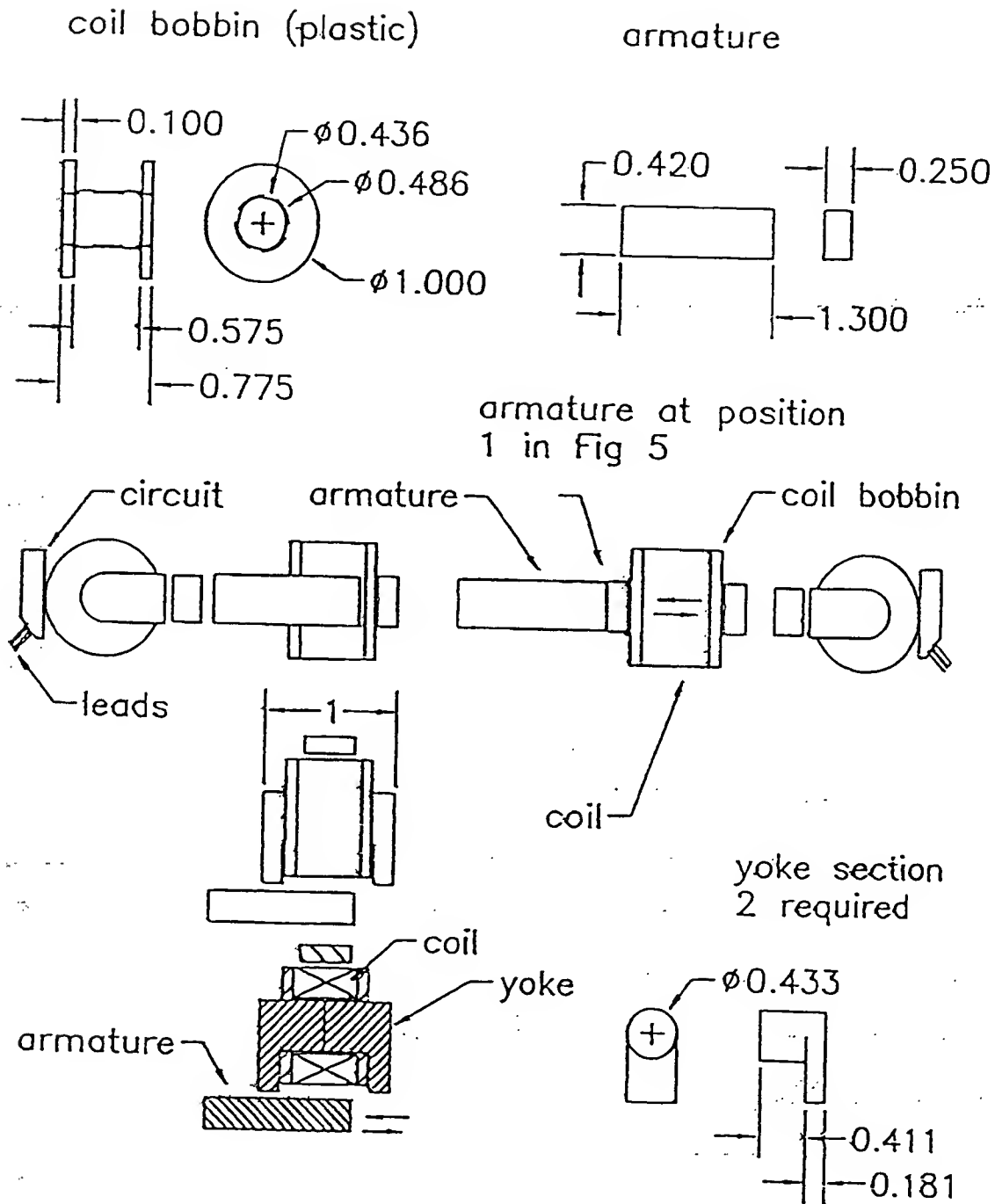


Fig 4

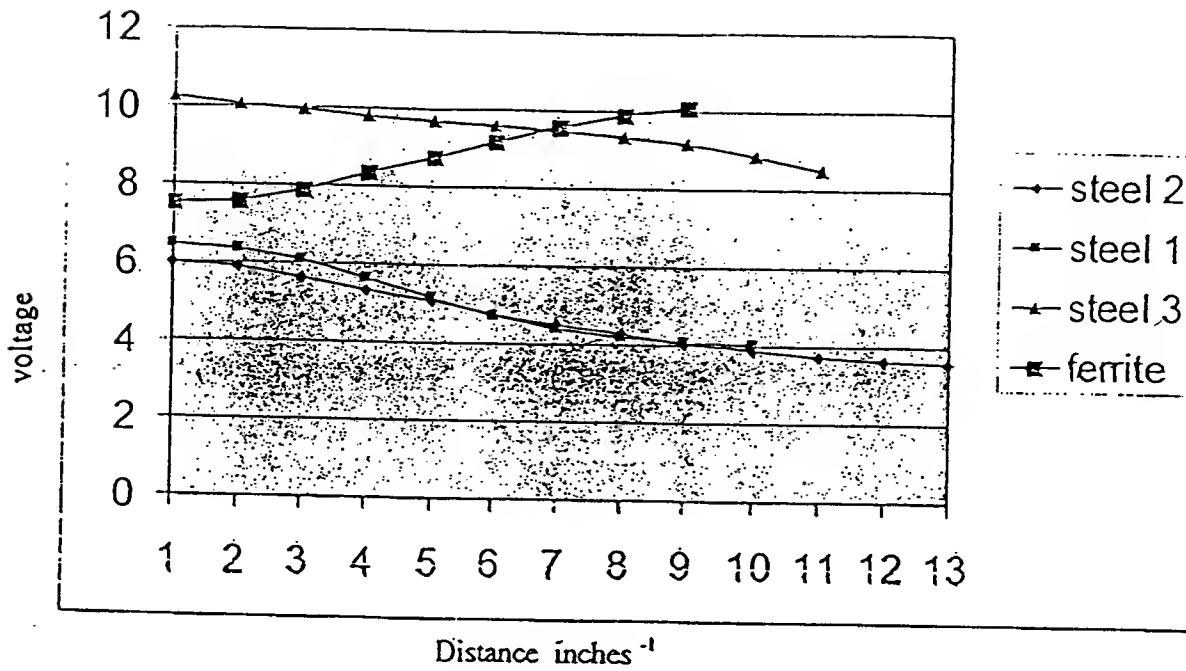


Fig 5

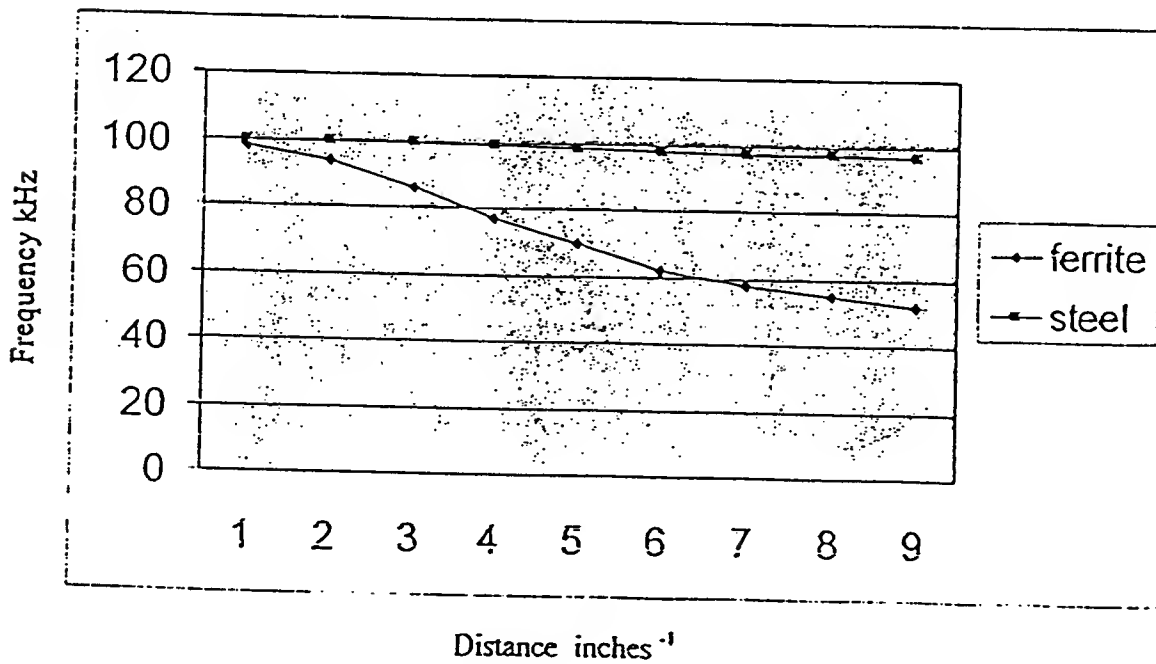


Fig 6

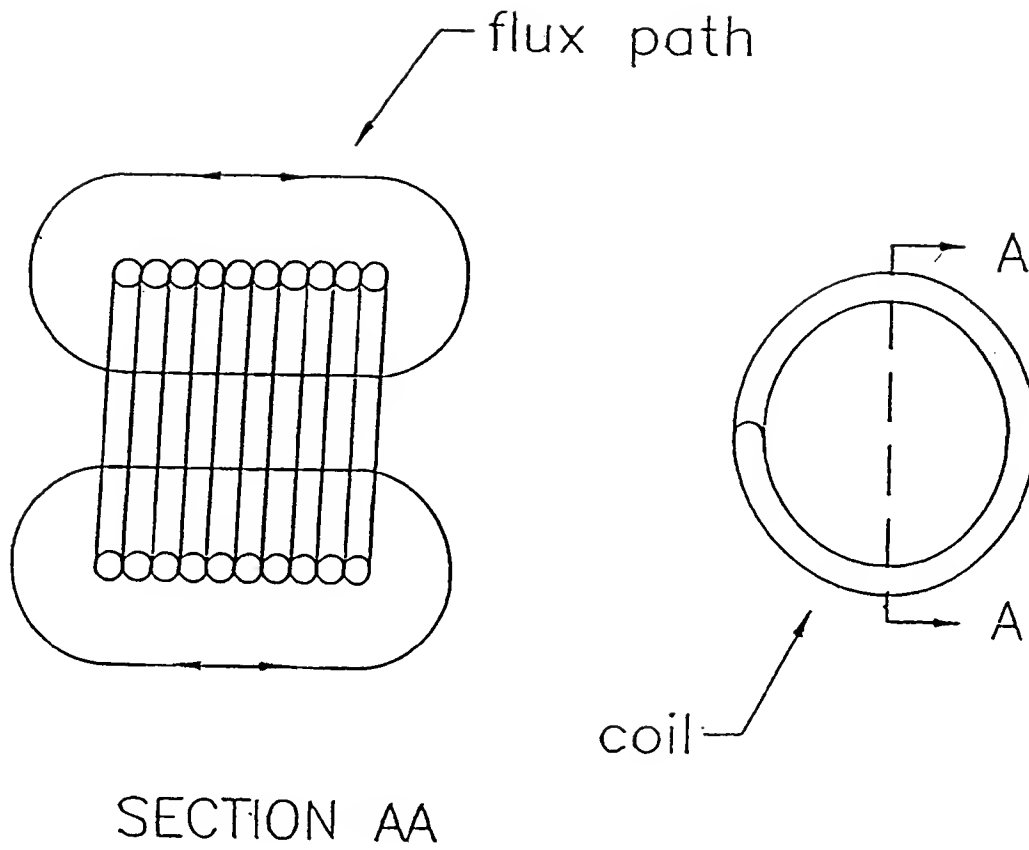


Fig 7.

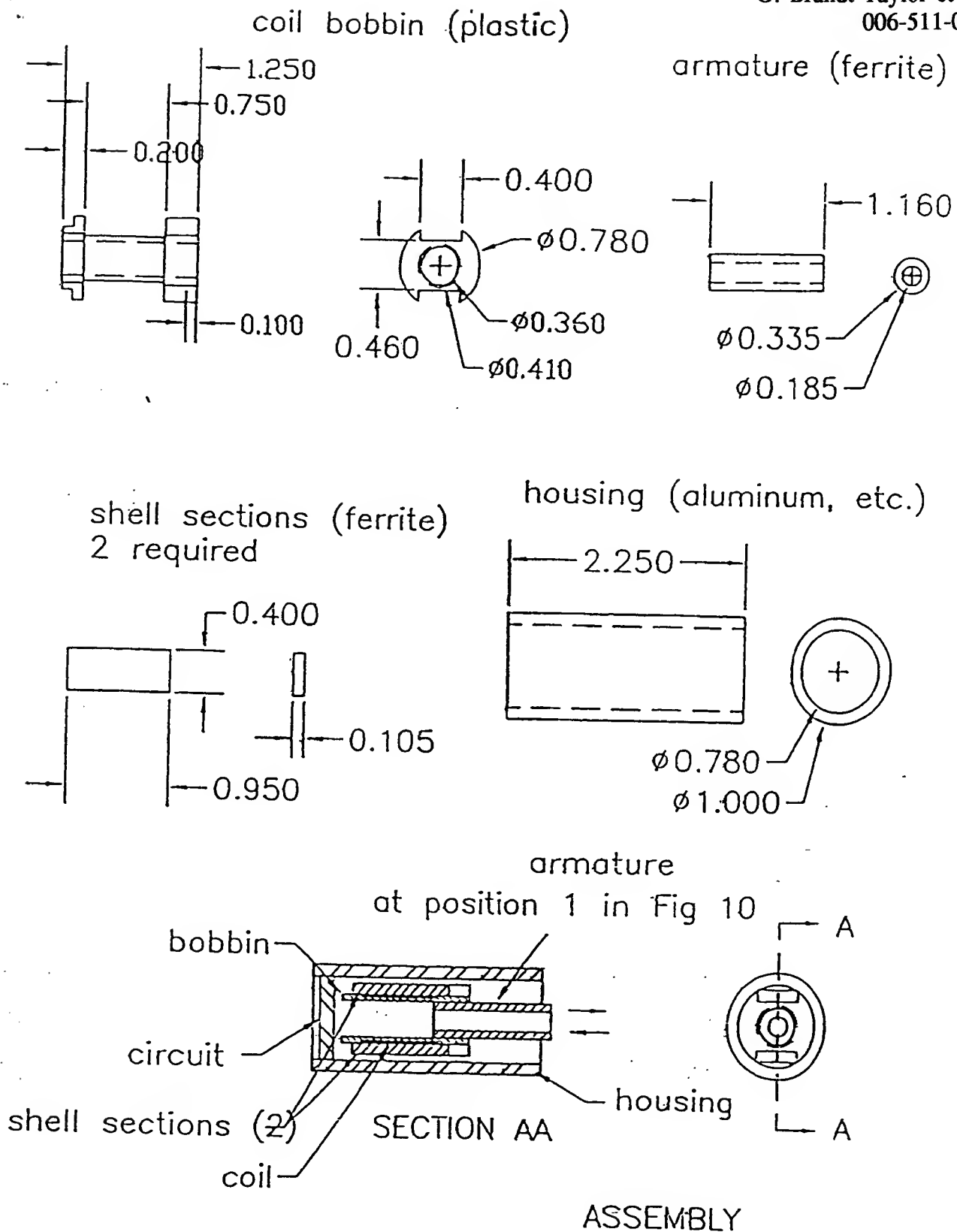
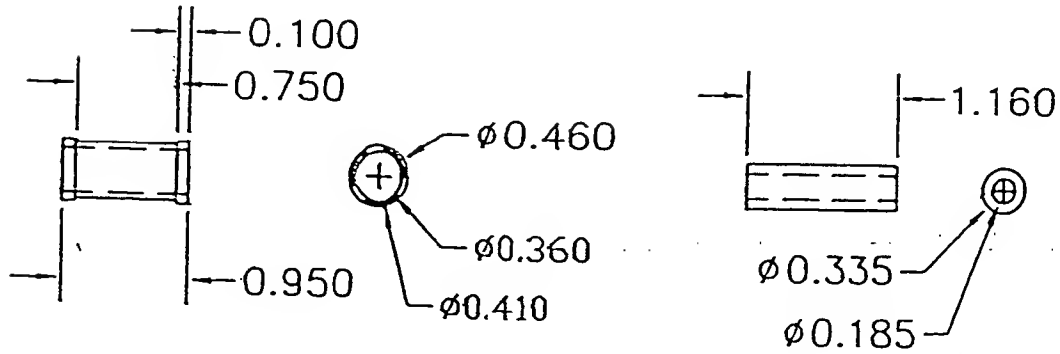


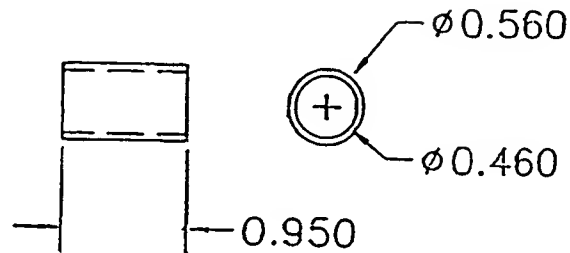
Fig 8

coil bobbin (plastic)

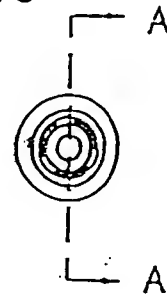
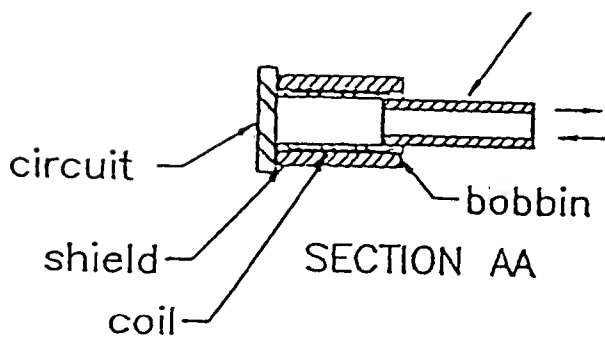
armature (ferrite)



shield (ferrite).



armature  
at position 1 in Fig 10



ASSEMBLY

Fig 9

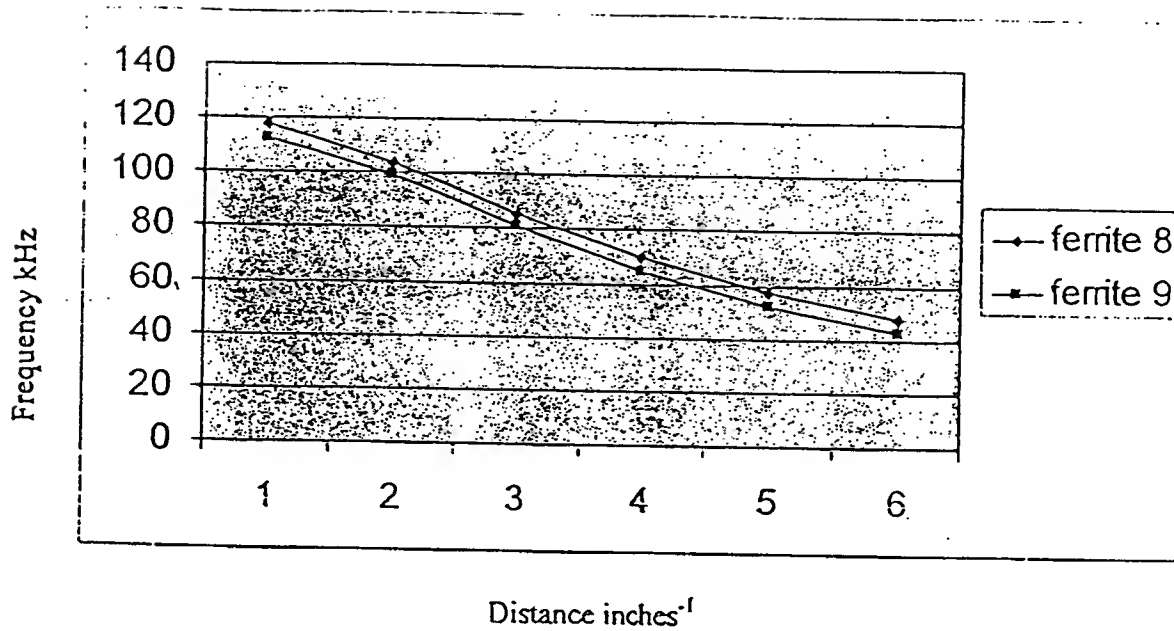


Fig 10

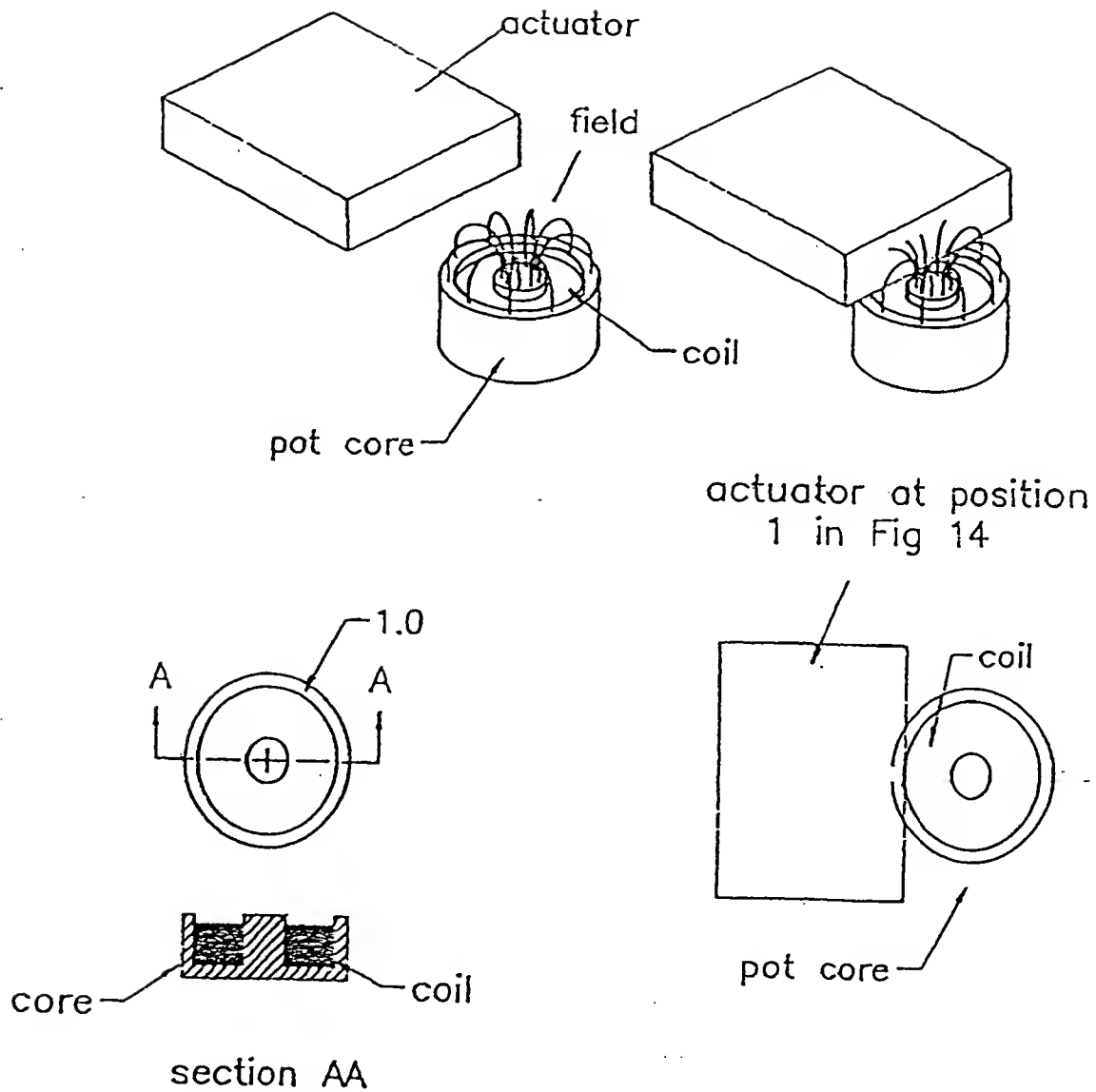


Fig 11

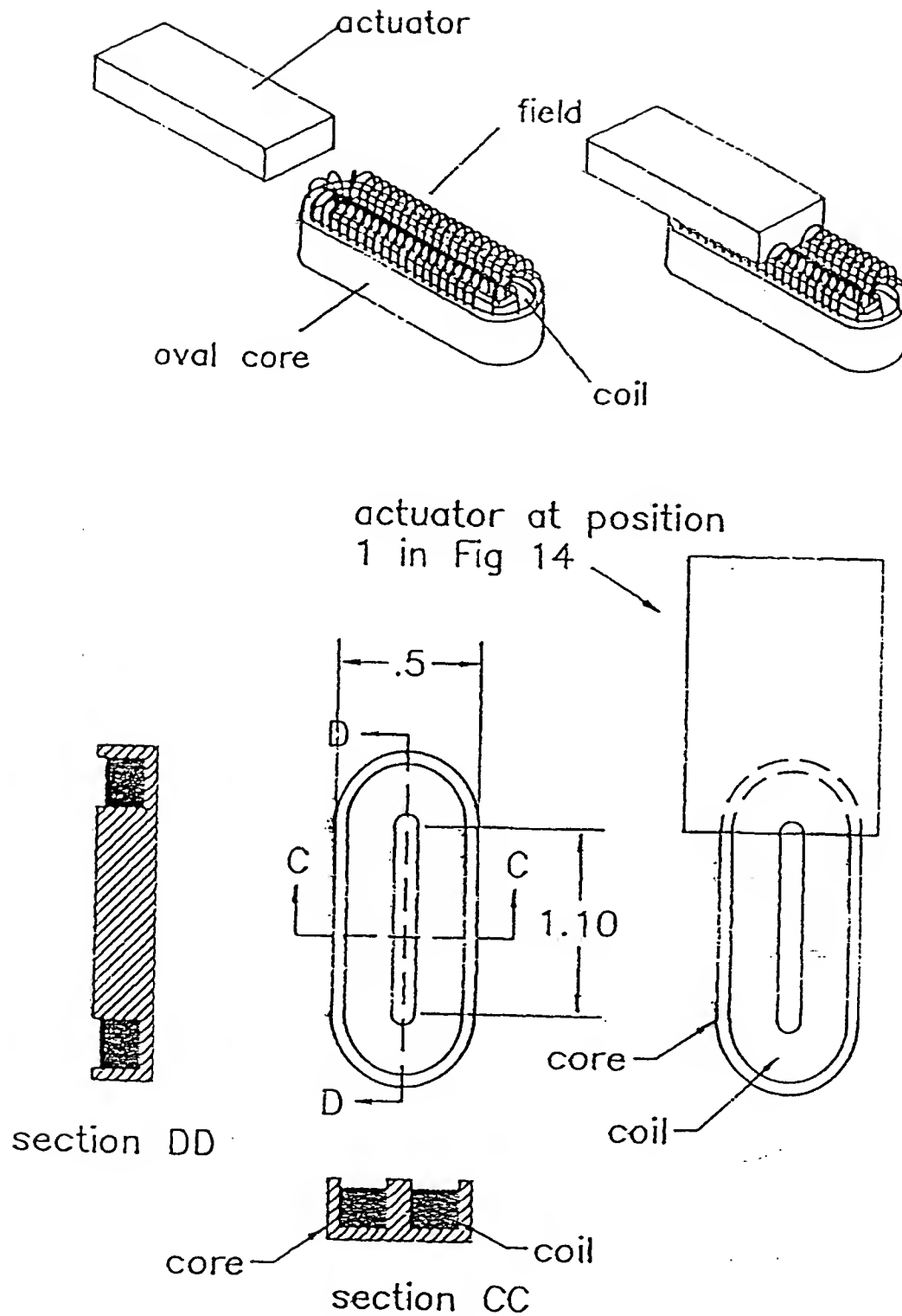


Fig 12

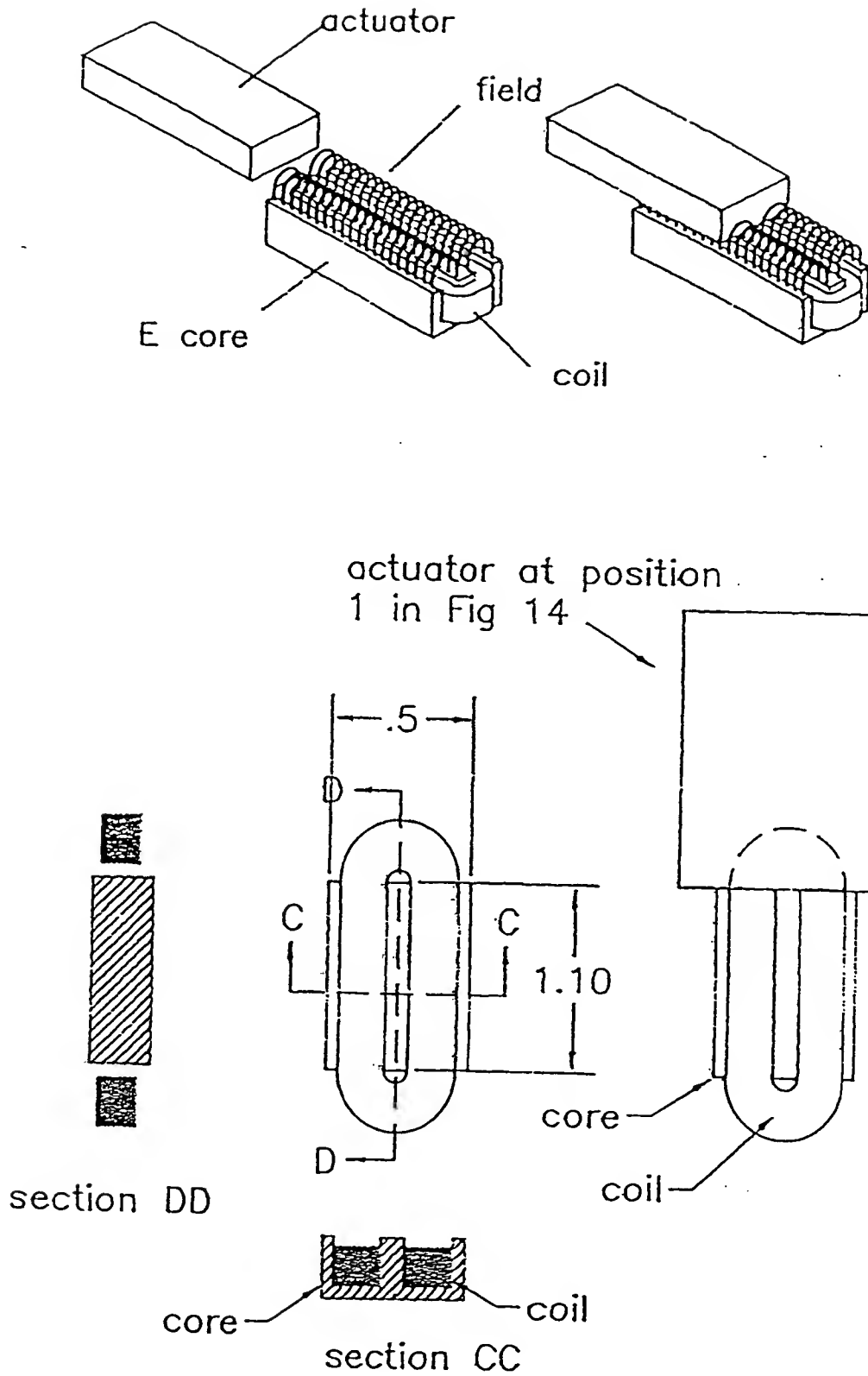


Fig 13

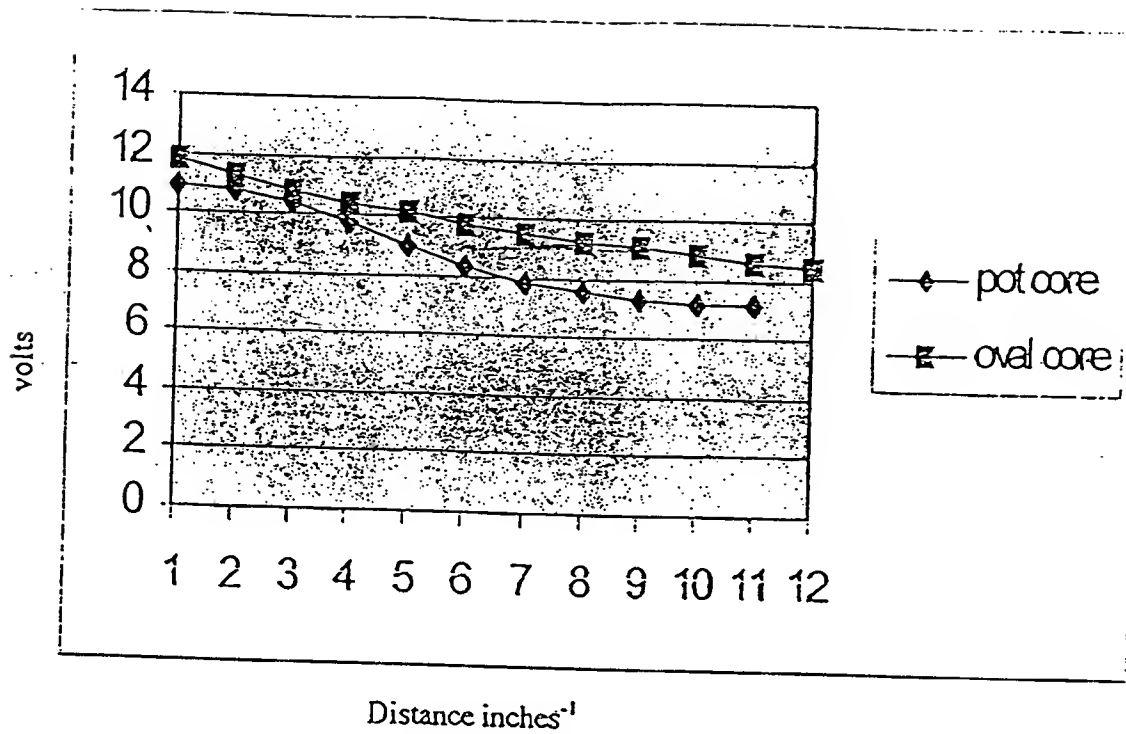


Fig 14

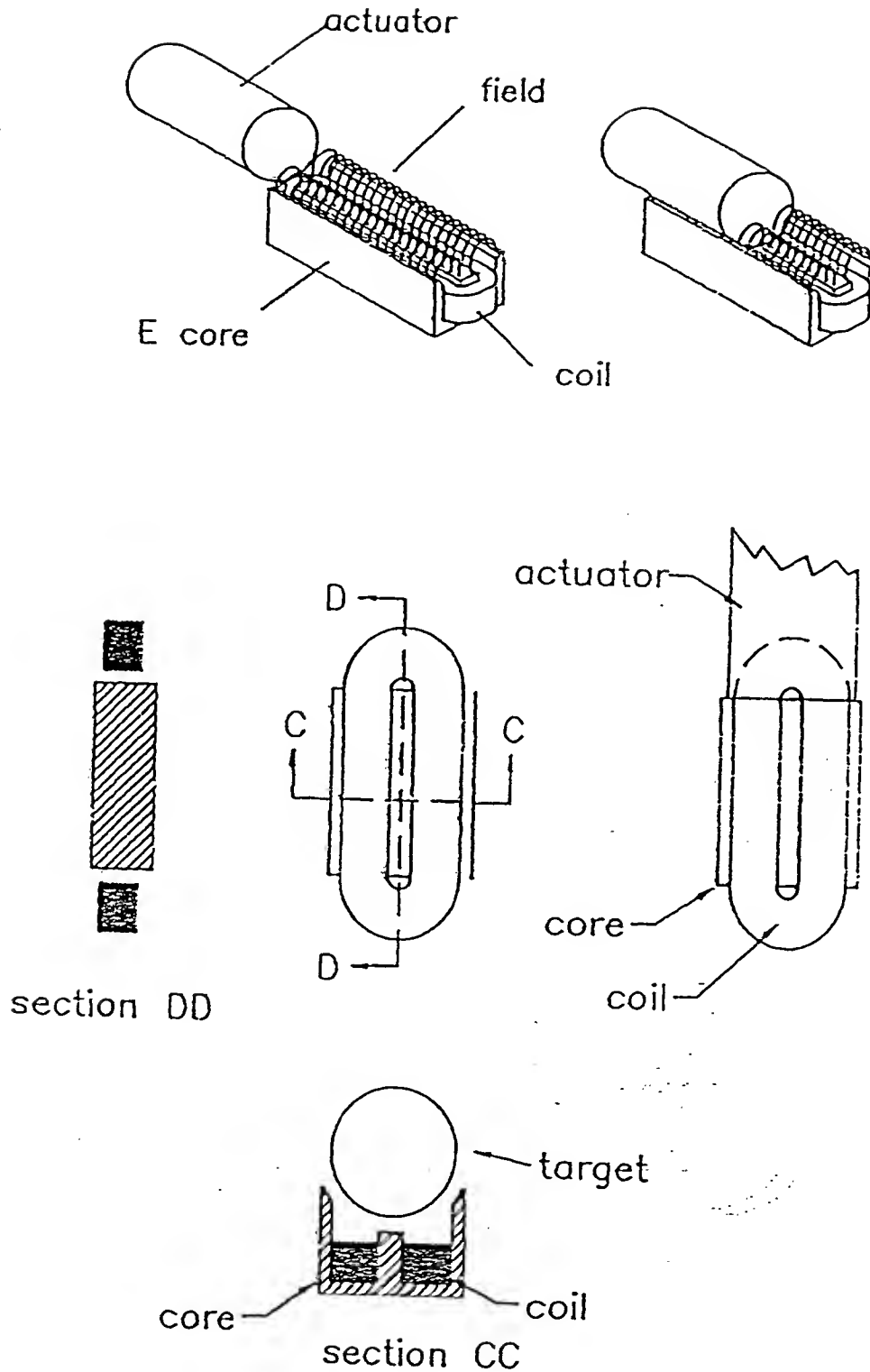


Fig 15

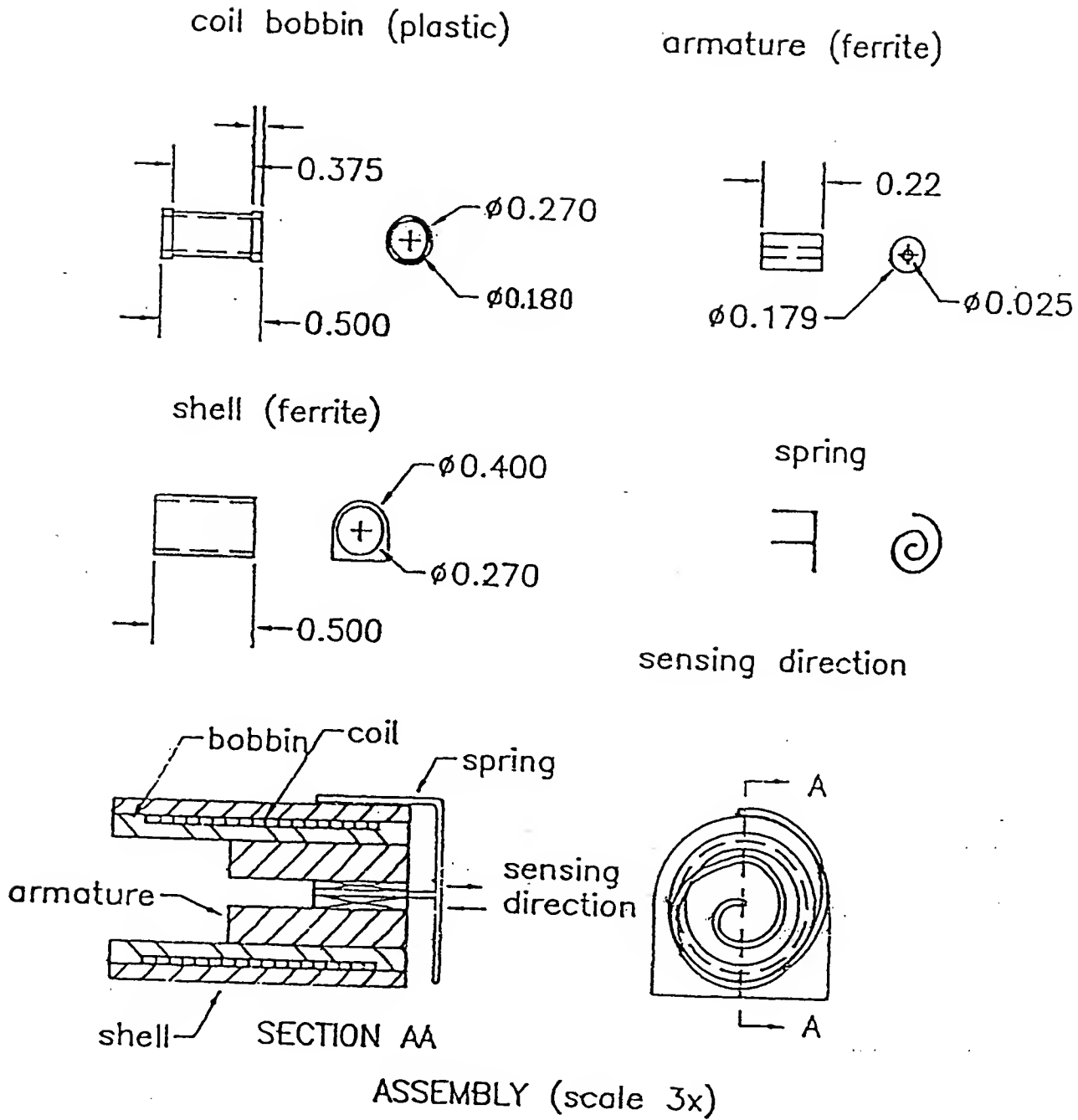


Fig 16

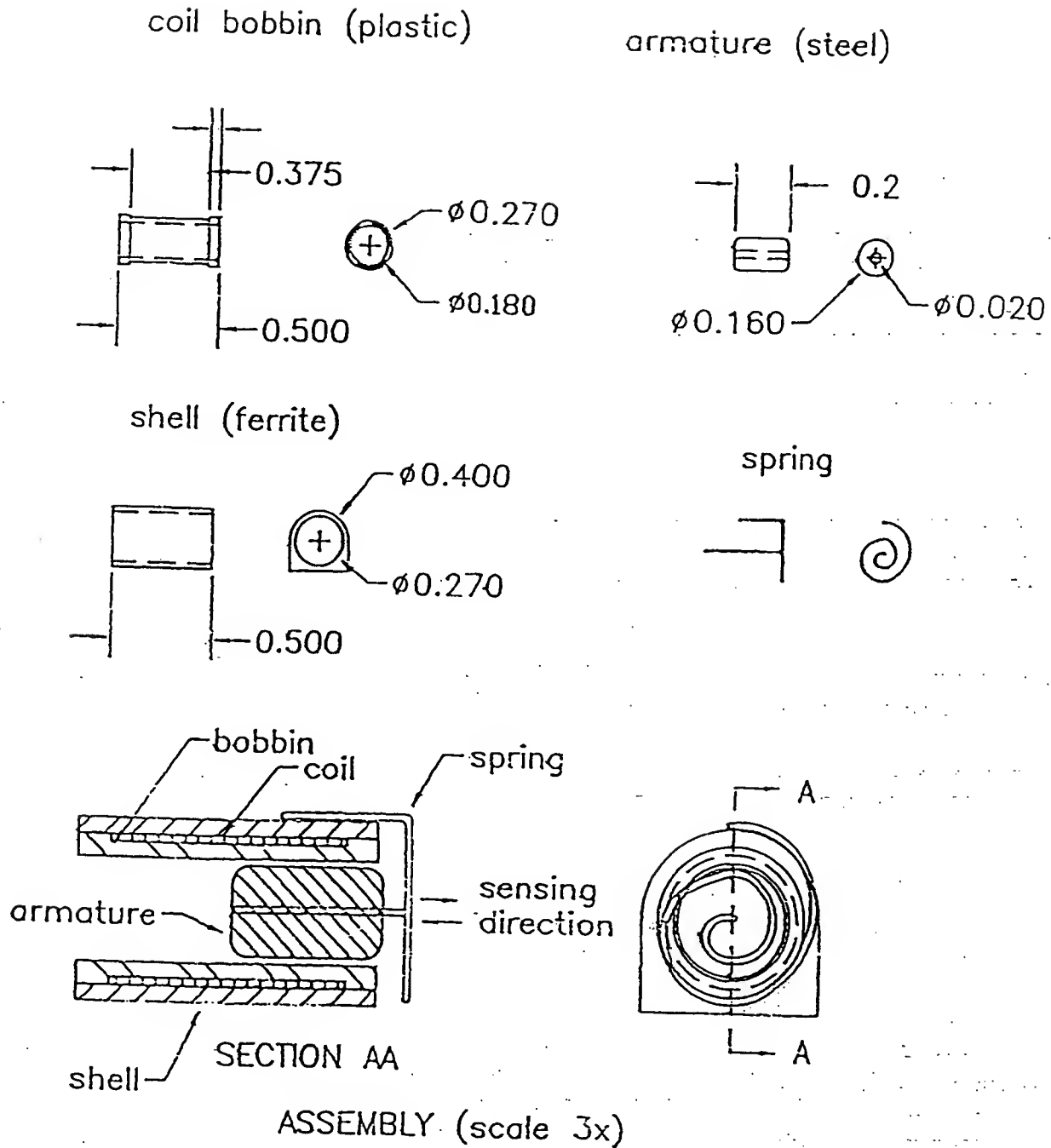


Fig 17

# Rotary Position Resolver

## Reference

1. United States Provisional Patent Application  
Taylor et al. "LINEAR POSITION AND MOTION SENSOR AND CIRCUIT"

## Abstract

Rotary position detectors are described that use sensor technology disclosed in Ref. 1.

Position sensors are described in Ref. 1 that project an electromagnetic field from a face of the sensor. Movement of a metal actuator across the face of the sensor causes a change in the electromagnetic field. Change in the field causes the circuit associated with the sensor to change its output. This change in output is used to indicate position of the actuator relative to the sensor. By making the actuator in a spiral or helical shape and attaching that actuator to a rotating shaft, rotary position of the shaft can be determined.

## Background

Various technologies are used for determining the angular position of an object about an axis of rotation. Optical, electrical, electrostatic and magnetic fields are all used with apparatus to measure position. There are many known apparatus for using these energies for sensing angular position. A few are resistive contacting sensors, inductively coupled ratio detectors, capacitively coupled ratio detectors, optical detectors using the Faraday effect, photo-activated ratio detectors, radio wave directional comparators, electrostatic ratio detectors and variable reluctance devices. There are many others.

The advancements disclosed in Ref 1 with regard to variable reluctance devices is exploited here with relation to rotary position sensing.

## Description

Fig 1 shows the sensor circuit of the present invention. The circuit has two main functional blocks, a regulated power supply and a tuned oscillator circuit.

The function of the regulated power supply is to allow the device to work on an input voltage of 8 – 50VDC. The positive voltage is applied to pin 3 of connector CT1 and ground (return) is applied to pin 1. An on board regulated +5VDC supply (U1) is used to power the oscillator functional block. This voltage regulator has a maximum input voltage of +16VDC. The transistor Q1 with the base voltage limited to 15VDC via the zener diode D1, keeps the input voltage to U1 below the maximum tolerance.

The tuned oscillator circuit is comprised of an amplifier (U2) and two reactive components, an inductor L1 and a capacitor C4. The frequency of the oscillator

$$F = \frac{1}{2 \pi \sqrt{LC}}$$

The amplifier U2 shown in Figure 1 is a high speed CMOS hex inverter. The resistor R2 is used to bias the input of the amplifier to compensate for the leakage current. The resistor R3 and capacitor C3 provide the feedback path. A transistor amplifier or operational amp will also work in place of hex inverter U2. The circuit shown in Figure 1 has two output signals, a sine wave (CT1 pin 2) and a DC voltage value (CT1 pin 4). The diode D2 and capacitor C5 rectify the sine wave output to a DC voltage value. The transistor Q2 is used to add some drive current to the DC voltage output signal. The inductor L1 is the coil in the sensors described here.

#### Sensor

Fig 2 shows a sensor of the type used in the current invention. The coil of the sensor is coil L1 in Fig 1. With this sensor the coil is mounted into a core made of a magnetic material (for example ferrite) that has an E shaped cross section. In operation an electromagnetic field is projected from the face of the sensor defined by the open side of the E shape. When the metal actuator moves into the field, eddy currents are created in the actuator that interfere with the field. Inductor resistance is increased causing the voltage output of the circuit to decrease. An example of this change in output of the circuit as the actuator intersects more and more of the field produced by the sensor is depicted in Fig 3.

#### Rotary motion resolution

Fig 4 shows actuator and sensor arrangement for resolving rotary motion. A sensor of the type of Fig 2 is rigidly affixed to a mount. A shaft protrudes through a hole in the mount and is able to rotate in the hole. The shaft is not able to move axially in the hole. An actuator plate is affixed rigidly to the shaft so that the planar surfaces of the actuator plate are perpendicular to the axis of the shaft. The outside edge of the metal actuator plate has a spiral shape. When the shaft and actuator assembly rotates about the axis of the shaft a greater or lesser amount of metal interacts with the field produced by the sensor. This causes the output of the sensor circuit to change. By judicious choice of the shape of the actuator the output of the sensor circuit can be adjusted for various angular displacements of the shaft. The output may be made linear with angular movement or it may be made to have abrupt changes and/or plateaus. The design of the actuator in Fig 4 might be used with a shaft that rotates alternately clockwise and counter clockwise over an angle of less than 360 degrees. In that case, one particular voltage value will be output by the circuit for any particular angular location of the shaft. Position of the actuator-shaft assembly will be detected when it is moving and when it is at rest.

Fig 5 shows an alternate design for an actuator plate. An actuator plate of this shape might be used when the shaft to which it is attached rotates for 360 degrees or more. In this case when the shaft is rotated for 360 degrees the output of the circuit will fluctuate from its high value to its low value and back to its high value. Position of the plate at rest is only known at the angular position corresponding to the high voltage reading and to the position at the low voltage reading. Otherwise there are two angular positions that have the same voltage output. However, if the shaft always rotates in one direction, either clockwise or counterclockwise, then angular position can be determined once there is rotation of the shaft. Once rotation occurs, then voltage is either increasing or decreasing. The voltage output value and the fact of increasing or decreasing voltage allows the circuit that receives output from the circuit of Fig 1 to identify angular position. Alternately, an electronic latch can be used that latches at the high voltage and unlatches at the low voltage or vice versa. Then combination of the latch state and voltage value of the circuit of will indicate position of the actuator-shaft assembly.

In Fig 4 and Fig 5 actuators are shown that have an actuator surface that moves radially in relation to the axis of rotation. Fig 6 and Fig 7 show actuators that have actuator faces that move axially with rotation of the actuator-shaft assembly. The output of the device depicted in Fig 6 is similar to the output of the device depicted in Fig 4. The output of the device depicted in Fig 7 is similar to the output of the device depicted in Fig 5.

Sensors of the type depicted in Fig 2 and used here are sensitive to motion of the actuator in the direction perpendicular to the face on the sensor. One application where the device shown in Fig 4 might find application is for detecting angular position of throttle shafts used with internal combustion engines. However, axial run out of throttle shafts is inherent in the design of the mechanisms currently in use. Fig 8 shows a device that compensates electronically for axial run out of the shaft. Two sensors of the type used in Fig 4 are rigidly held in a mount so that they face each other and are parallel to each other. The actuator plate is mounted midway between the two sensors. Axial movement of the actuator-shaft assembly causes the inductive resistance of one sensor coil to decrease while causing the other sensor coil to have an increase in inductive resistance. By summing the inductive resistance of the two coils, here called L1 and L2, the effect of axial movement of the actuator-shaft assembly on voltage output of the device is reduced.

Fig 9 shows the two coils wired in series in the circuit of Fig 1. Fig 10 shows the coils wired in parallel. Both ways are effective in lessening the effect of axial run out of the shaft.

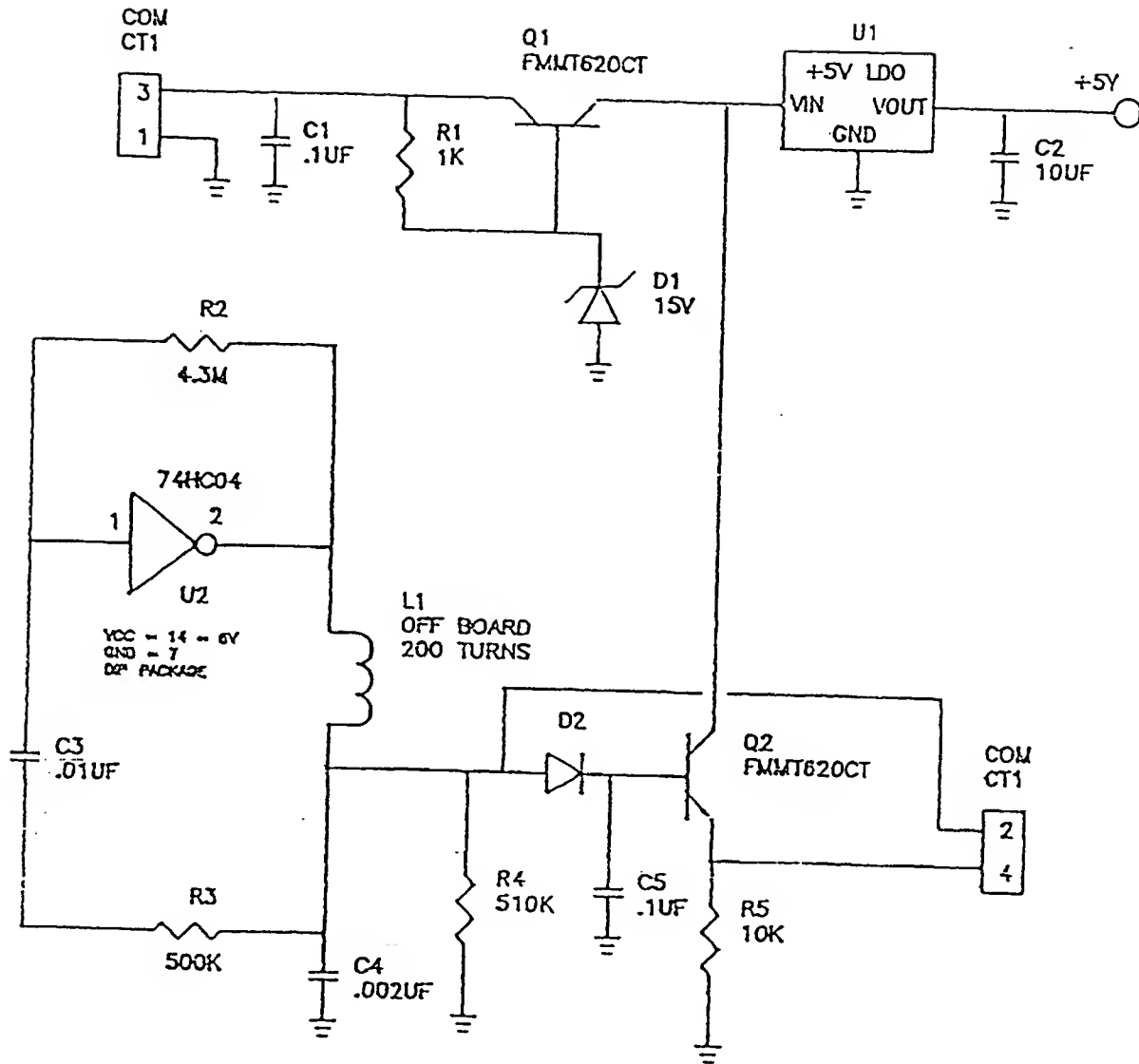


Fig 1

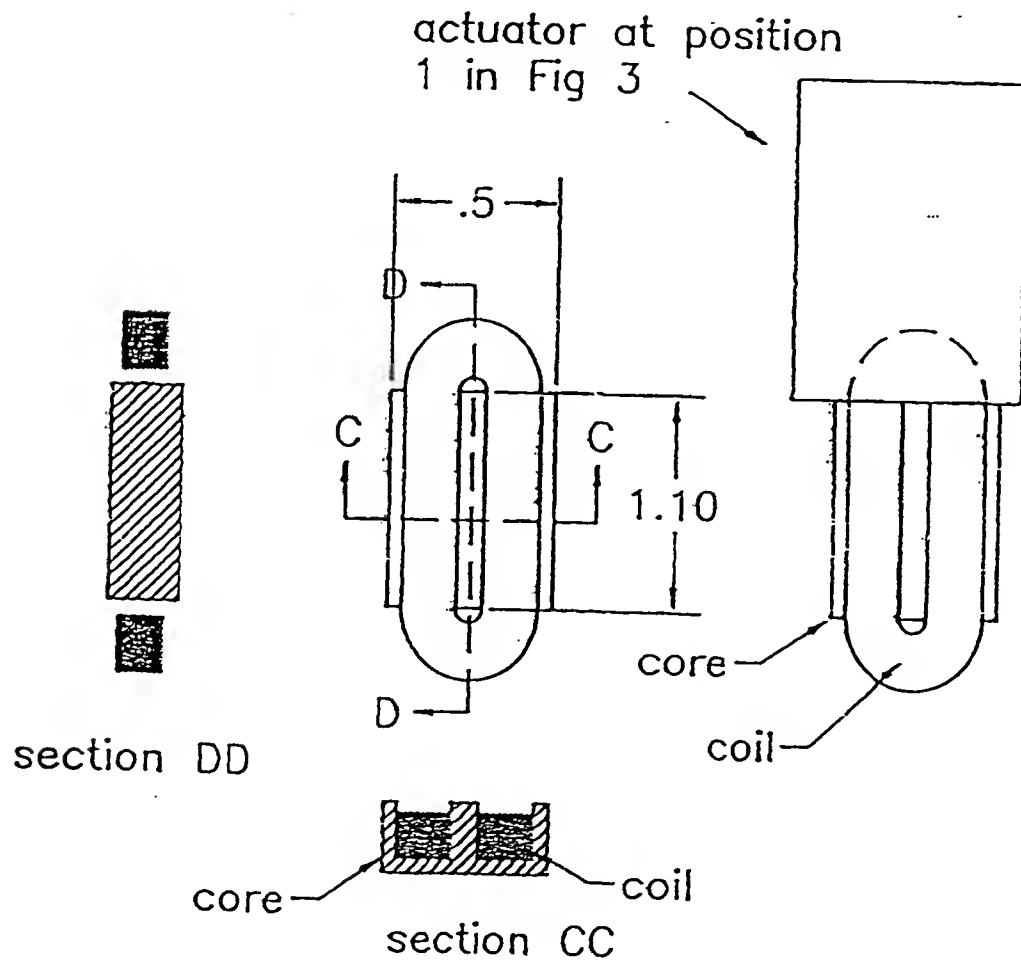
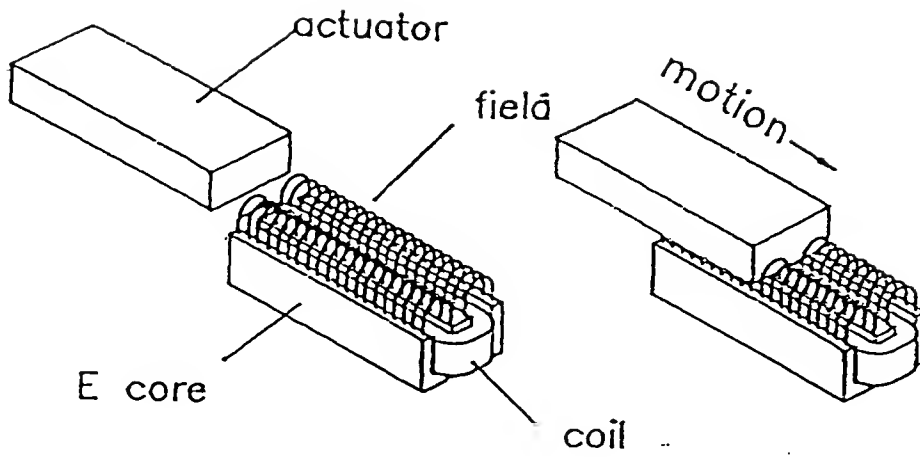


Fig 2

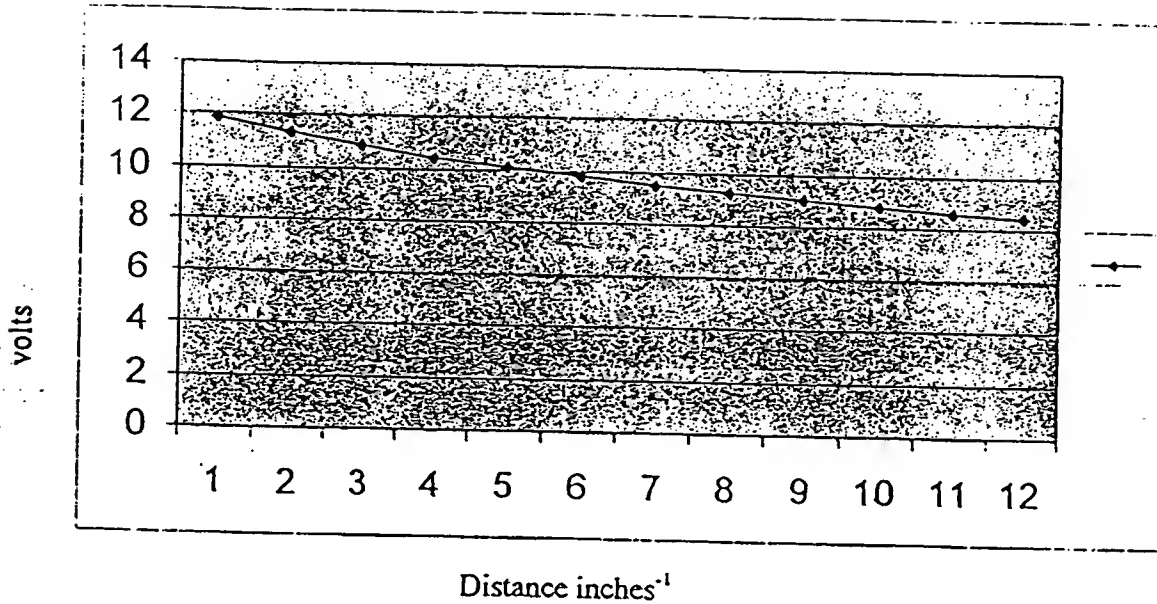


Fig 3

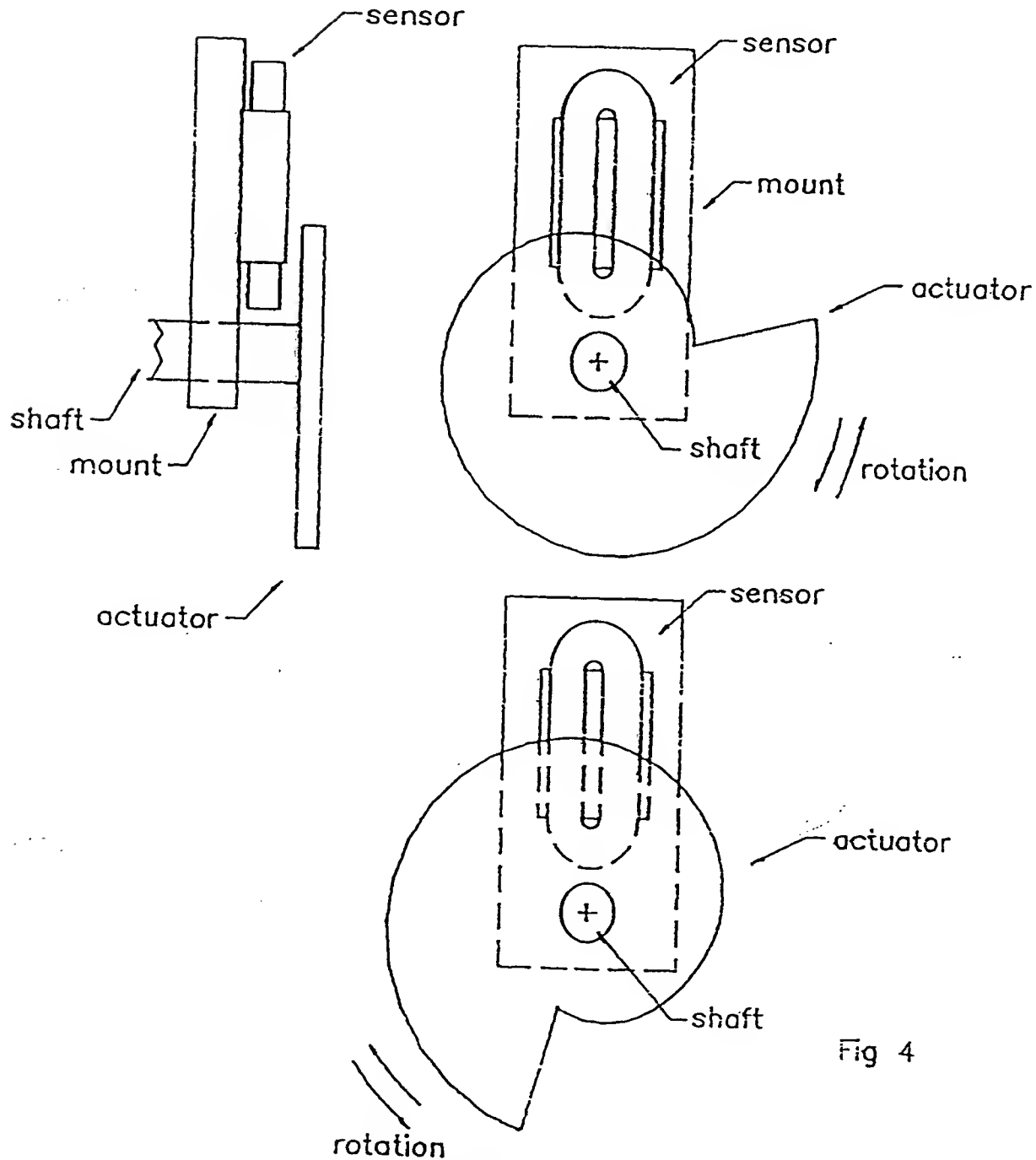
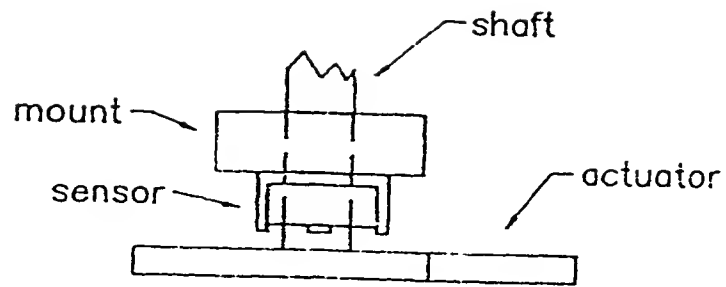


Fig 4

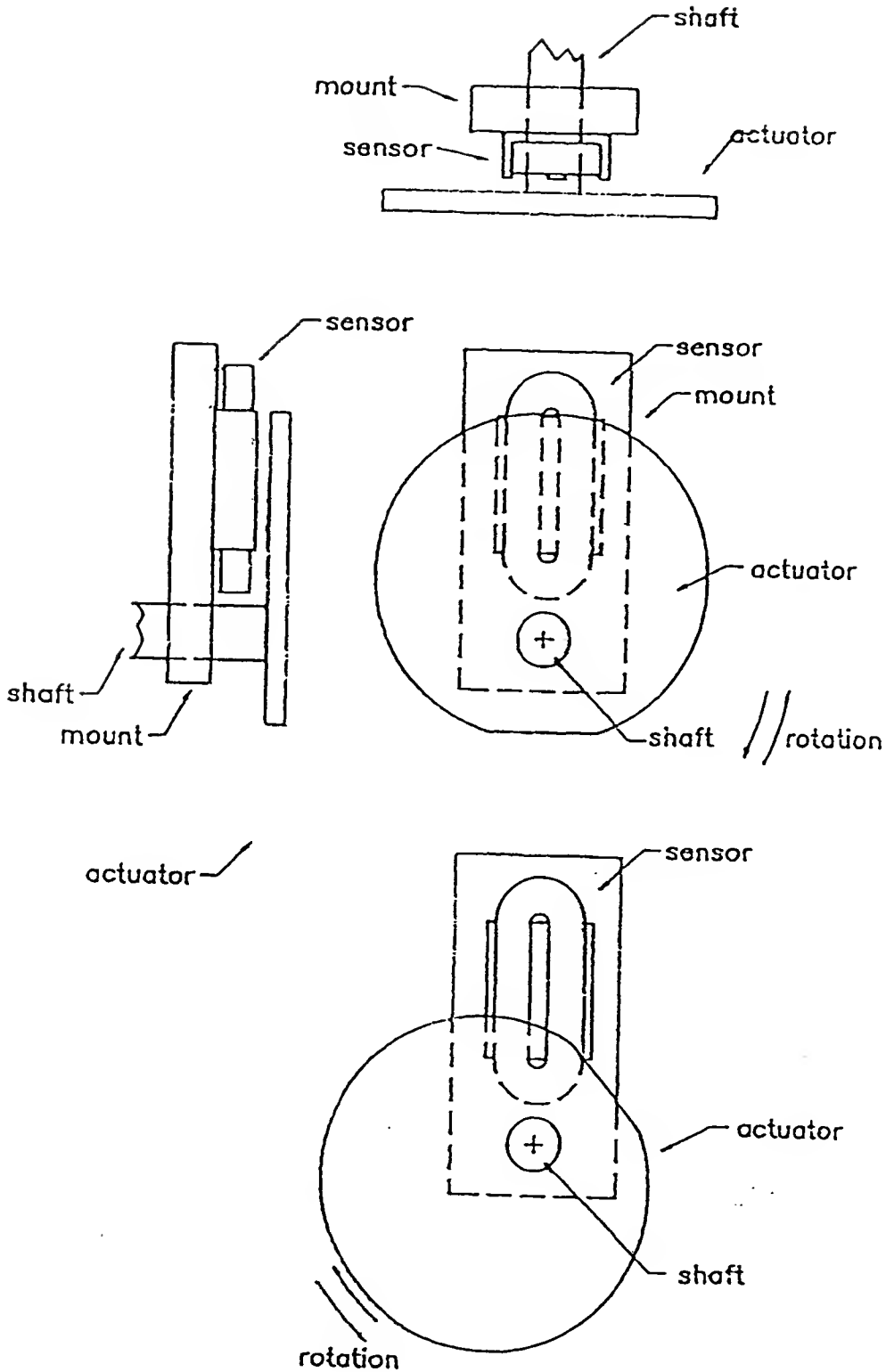


Fig 5

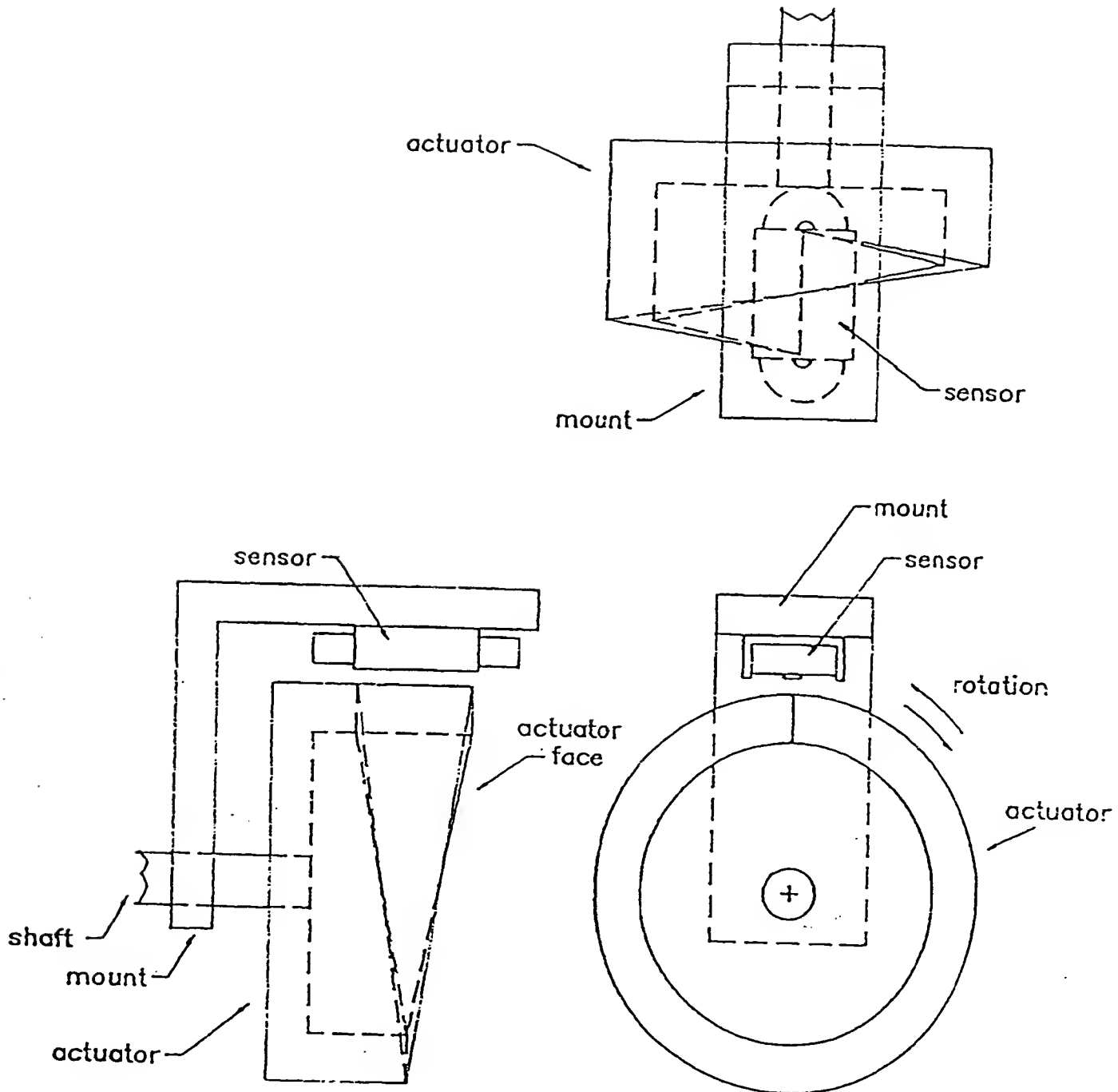


fig 6

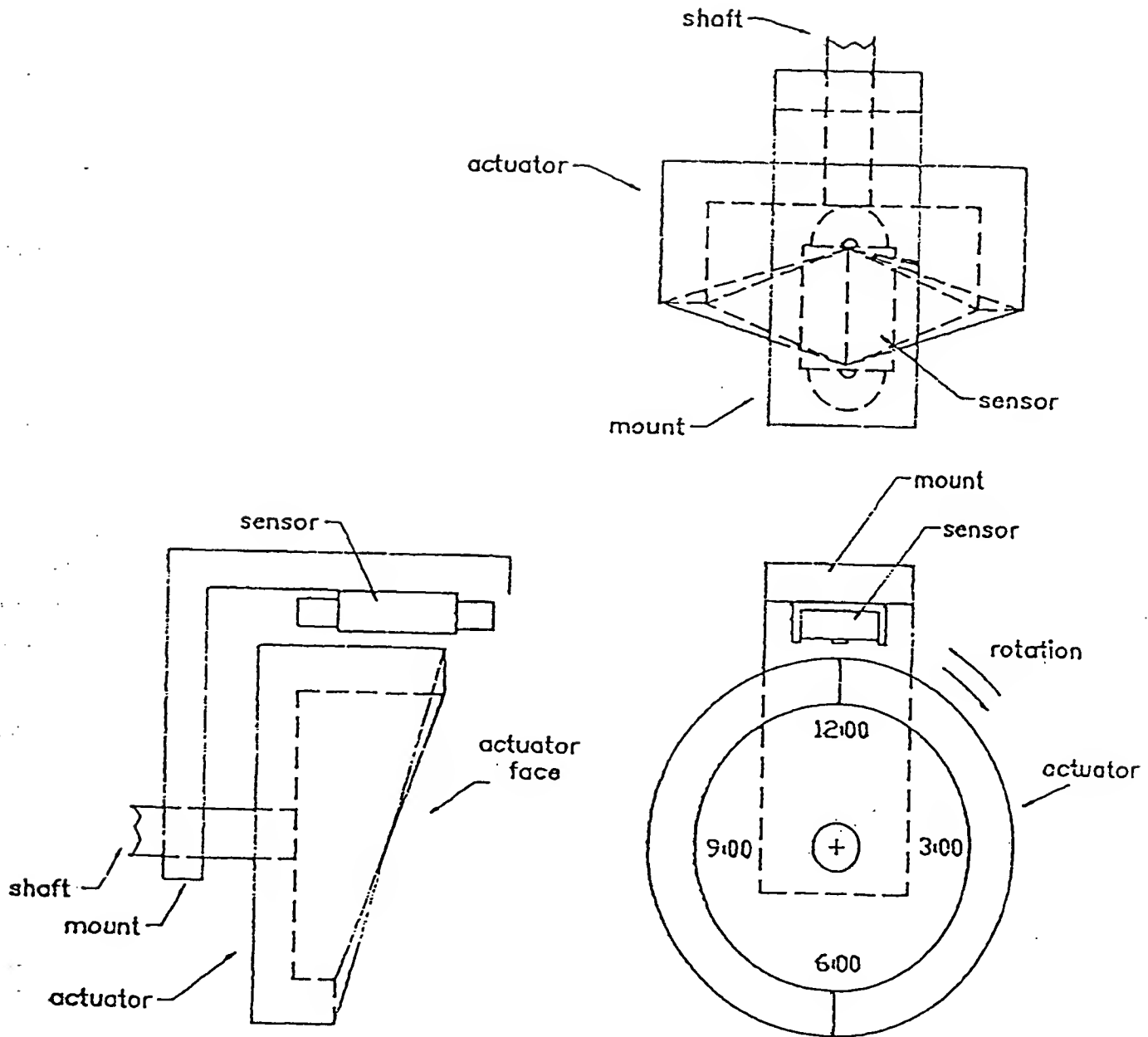
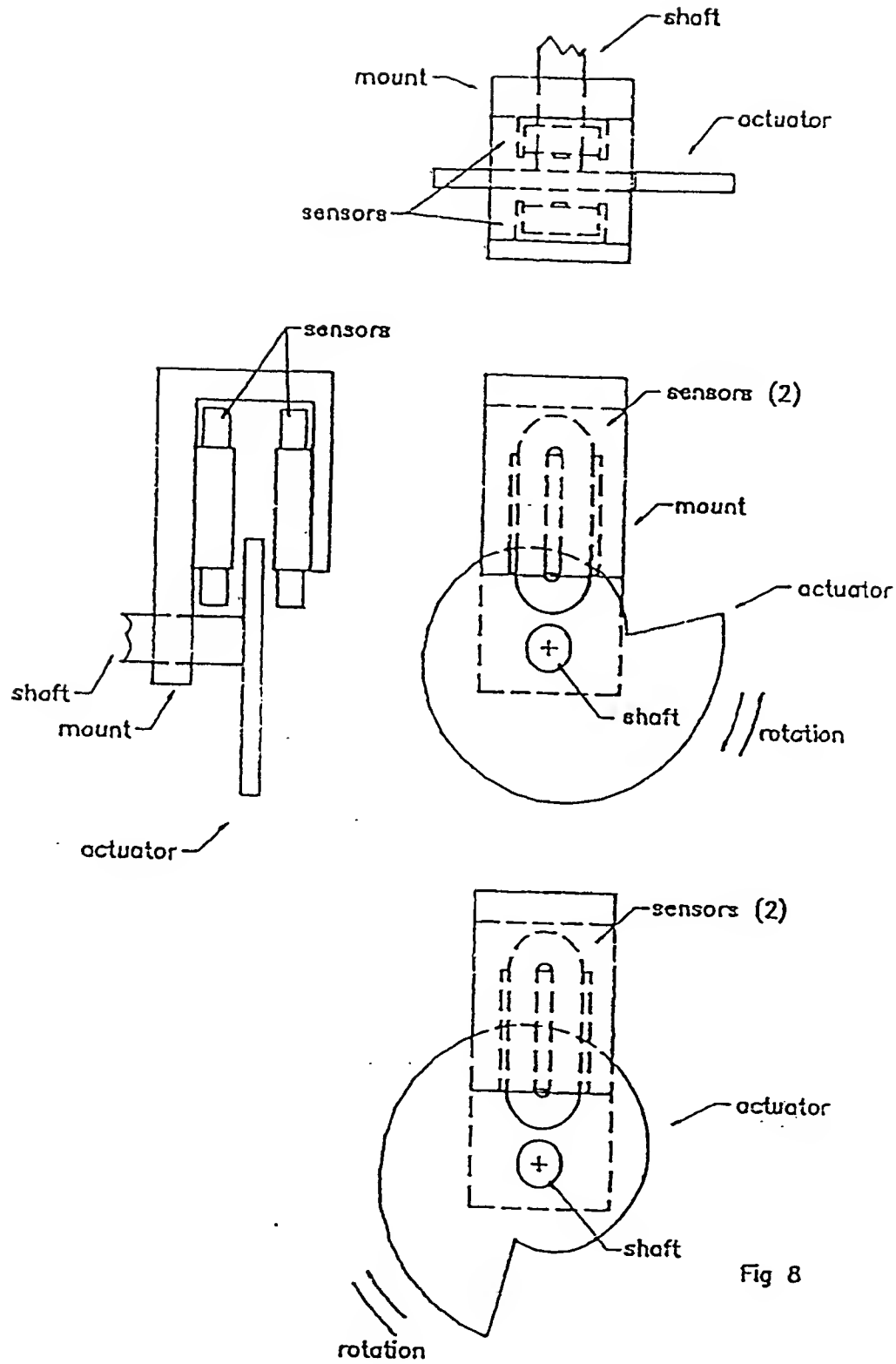
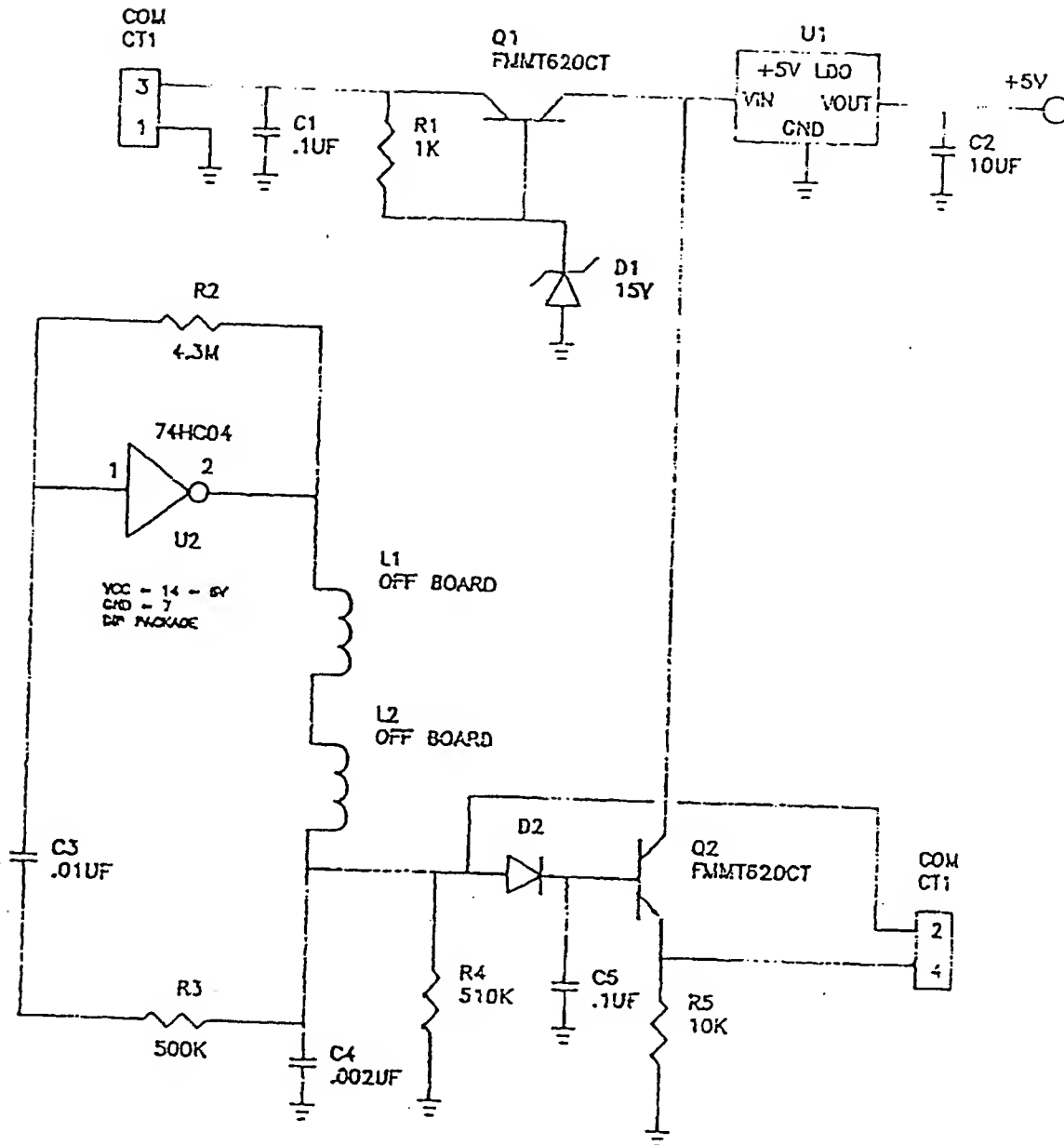


fig 7





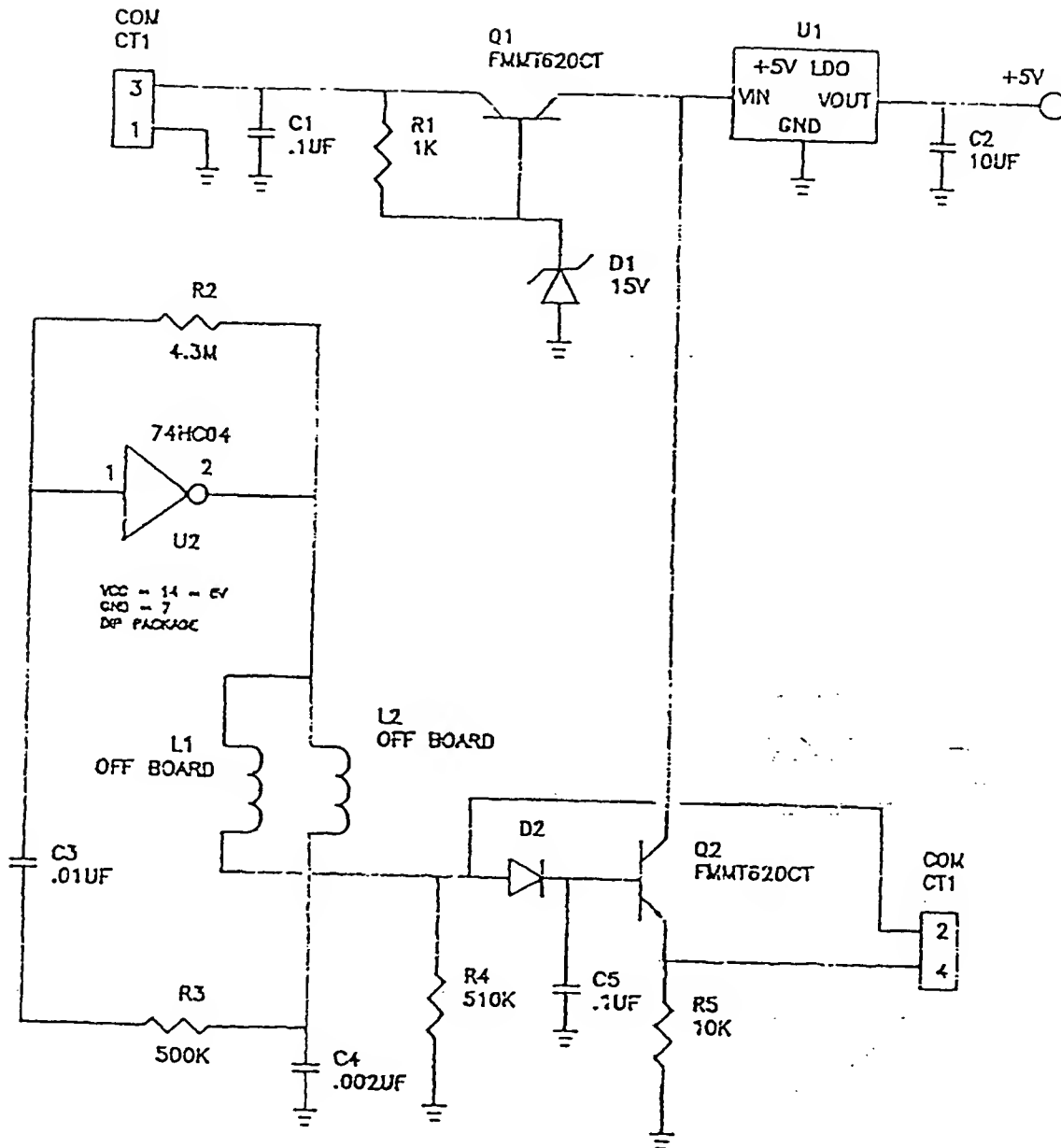


Fig 10

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